HAZARD MAPPING OF THE PHILIPPINES USING LIDAR (PHIL-LIDAR I)

LiDAR Surveys and Flood Mapping of Pulot River

University of the Philippines Training Center
for Applied Geodesy and Photogrammetry
University of the Philippines Los Baños

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Asian Aerospace Corporation
Ab	abutment
ALTM	Airborne LiDAR Terrain Mapper
ARG	automatic rain gauge
ATQ	Antique
AWLS	Automated Water Level Sensor
BA	Bridge Approach
BM	benchmark
CAD	Computer-Aided Design
CN	Curve Number
CSRS	Chief Science Research Specialist
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
DOST	Department of Science and Technology
DPPC	Data Pre-Processing Component
DREAM	Disaster Risk and Exposure Assessment for Mitigation [Program]
DRRM	Disaster Risk Reduction and Management
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVBC	Data Validation and Bathymetry Component
FMC	Flood Modeling Component
FOV	Field of View
GiA	Grants-in-Aid
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center - River Analysis System
HC	High Chord
IDW	Inverse Distance Weighted [interpolation method]
IMU	Inertial Measurement Unit
kts	knots
LAS	LiDAR Data Exchange File format
LC	Low Chord
LGU	local government unit
LiDAR	Light Detection and Ranging
LMS	LiDAR Mapping Suite
m AGL	meters Above Ground Level
MMS	Mobile Mapping Suite
MSL	mean sea level
NAMRIA	National Mapping and Resource Information Authority
NSTC	Northern Subtropical Convergence
PAF	Philippine Air Force
PAGASA	Philippine Atmospheric Geophysical and Astronomical Services Administration
PDOP	Positional Dilution of Precision
PPK	Post-Processed Kinematic [technique]
PRF	Pulse Repetition Frequency
PTM	Philippine Transverse Mercator
QC	Quality Check
QT	Quick Terrain [Modeler]
RA	Research Associate
RIDF	Rainfall-Intensity-Duration-Frequency
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
SRS	Science Research Specialist
SSG	Special Service Group
TBC	Thermal Barrier Coatings
UPLB	University of the Philippines Los Baños
UP-TCAGP	University of the Philippines – Training Center for Applied Geodesy and Photogrammetry
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER 1: OVERVIEW OF THE PROGRAM AND THE PULOT RIVER

Enrico C. Paringit, Dr. Eng. and Dr. Edwin Abucay

1.1 Background of the Phil-LiDAR 1 Program

The University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP TCAGP) launched a research program in 2014 entitled "Nationwide Hazard Mapping using LiDAR" or Phil-LiDAR 1 in 2014, supported by the Department of Science and Technology (DOST) Grants-in-Aid (GiA) Program. The program was primarily aimed at acquiring a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management. Particularly, it targeted to operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country.

The program also aimed to produce an up-to-date and detailed national elevation dataset suitable for 1:5,000 scale mapping, with 50 cm and 20 cm horizontal and vertical accuracies, respectively. These accuracies were achieved through the use of the state-of-the-art Light Detection and Ranging (LiDAR) airborne technology procured by the project through DOST. The methods applied in this report are thoroughly described in a separate publication titled Flood Mapping of Rivers in the Philippines Using Airborne LiDAR: Methods (Paringit et al., 2017) available separately.

The implementing partner university for the Phil-LiDAR 1 Program is the University of the Philippines Los Baños (UPLB). UPLB is in charge of processing LiDAR data and conducting data validation reconnaissance, cross section, bathymetric survey, validation, river flow measurements, flood height and extent data gathering, flood modeling, and flood map generation for the 45 river basins in the Southern Luzon Region. The university is located in the City of Los Baños in the province of Laguna.

1.2 Overview of the Pulot River Basin

The Pulot River Basin, a 173,600-hectare watershed, covers one (1) municipality in Palawan; namely, the Municipality of Brookes Point. It covers the barangays of Calasaguen in Brooke's Point municipality; Sowangan and Tagusao in Quezon; and Iraray, Labog, Pulot Center, Pulot Interior, Pulot Shore and Punang in Sofronio Española.

IBased on the studies conducted by the Mines and Geosciences Bureau, only Pulot Shore have flood susceptibility (low to high) while rest of the other barangays have no flood hazard at all. The field surveys conducted by the Phil-LiDAR 1 validation team found that four (4) notable weather disturbance caused flooding in 2009 (Ondoy), 2013 (Yolanda), and 2016 (Dindo, Karen and Nina). On the other hand, Calasaguen, Pulot Center and Pulot Interior have low to high susceptibilitiesto landslides. The rest of the barangays have low landslide susceptibility.

On November 17, 2016, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) issued a flood advisory for Pulot River and its tributaries due to the moderate to heavy rains brought by the presence of a trough of low pressure area affecting Southern Luzon, Visayas and Mindanao as per NDRRMC report (NDRRMC 2016).

The DENR River Basin Control Office (RBCO) states that the Pulot River Basin has a drainage are of 177 km^2 and an estimated 283 cubic meter (MCM) annual run-off (RBCO, 2015).

The river basin is characterized by 30-50% slope.The soil types in the area include San Manuel clay loam and Brooke's clay loam. Other areas are still unclassified (rough mountainous land). Closed canopy (mature trees covering >50%) dominates the area followed by arable land (crops mainly cereals and sugar), crop land mixed with coconut plantation, cultivated area mixed with brushland/grassland, mossy forest and open canopy (mature trees covering <50%)

I

Its main stem, Pulot River, is among the 45 river systems in MIMAROPA Region. According to the 2015 national census of PSA, a total of 5,789 persons are residing in Brgy. Pulot Center in the Municipality of Sofronio Española, which is within the immediate vicinity of the river. The economy of the province of Palawan is primarily agriculture-based; particularly fishing, tourism, trade, commerce, and mineral extraction (Source: pkp.pcsd.gov.ph/images/ppcprofile/Economic%20Profile.pdf).

Pulot River passes through Calasaguen in Brooke's Point municipality; Iraray, Pulot Center, Pulot interior, Pulot Shore and Punang in Sofronio Espanola. Pulot Center is considered to be the most populated barangay based on the 2010 NSO Census of Population and Housing.

Climate Types I and III prevail in MIMAROPA and Laguna based on the Modified Corona Classification of climate. Type I has two pronounced seasons, dry from November to April, and wet the rest of the year

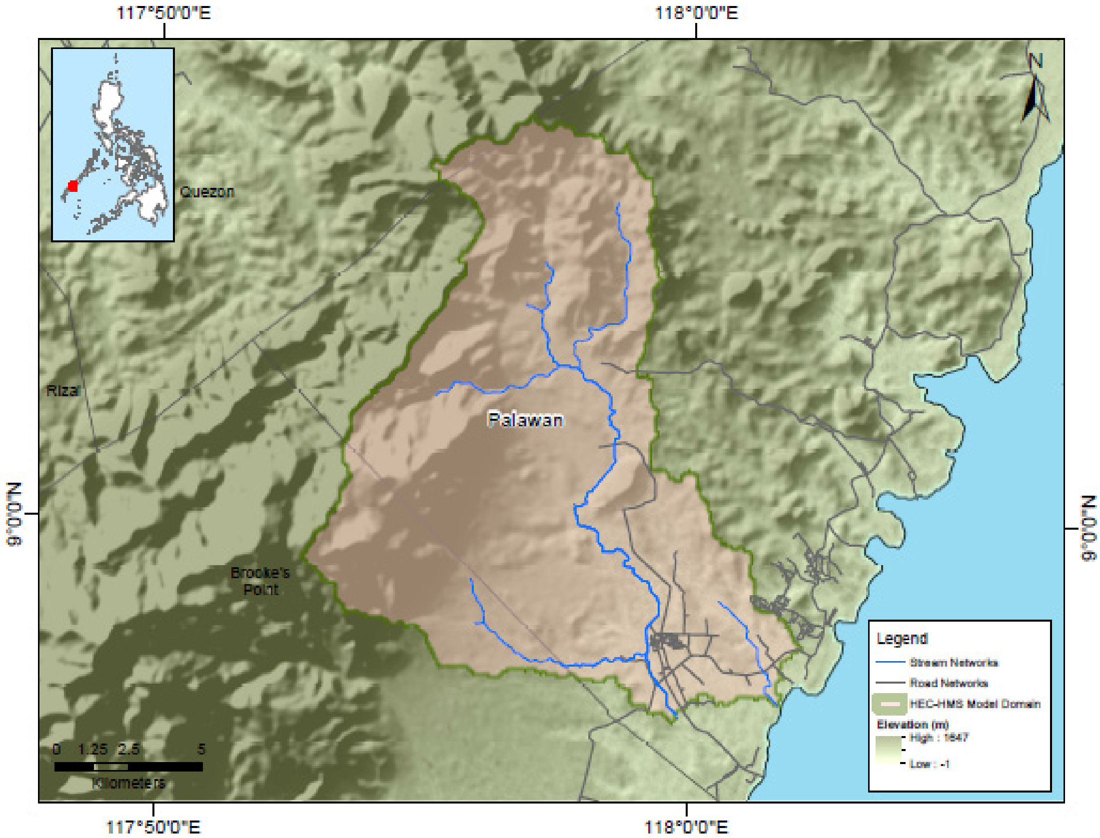

Figure 1. Map of Pulot River Basin (in brown)

Sources: LDRRM Office of Siay, Philippine Information Agency- IX, Mines and Geosciences Bureau- IX

CHAPTER 2: LIDAR ACQUISITION IN PULOT FLOODPLAIN

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The methods applied in this chapter were based on the DREAM methods manual (Sarmiento et al., 2014) and further enhanced and updated in Paringit et al. (2017).

2.1 Flight Plans

Plans were made to acquire LiDAR data within the delineated priority area for Pulot Floodplain in Palawan. These missions were planned for 12 lines that run for at most four and a half (4.5) hours including take-off, landing and turning time. The flight planning parameters for the LiDAR system is found in Table 1. Figure 2 shows the flight plans for Pulot Floodplain.

Table 1. Flight planning parameters for Gemini LiDAR system.

Block Name	Flying Height (AGL)	Overlap (%)	Field of View (θ)	Pulse Repetition Frequency (PRF) (kHz)	Scan Frequency (Hz)	Average Speed	Average Turn Time (Minutes)
BLK42L	600/850	30	50	100/125	40	130	5
BLK42M	600/850	30	50	100/125	40	130	5
BLK42eN	500/600/700/850 /1000	30	26/30/40 /50	100/125	40/50	130	5
BLK42eO	600/850	30	50	100/125	40	130	5
BLK42eP	600/850/1000	30	26/50	100/125	40/50	130	5
BLK42eQ	600/850/1000	30	26/50	100/125	40/50	130	5

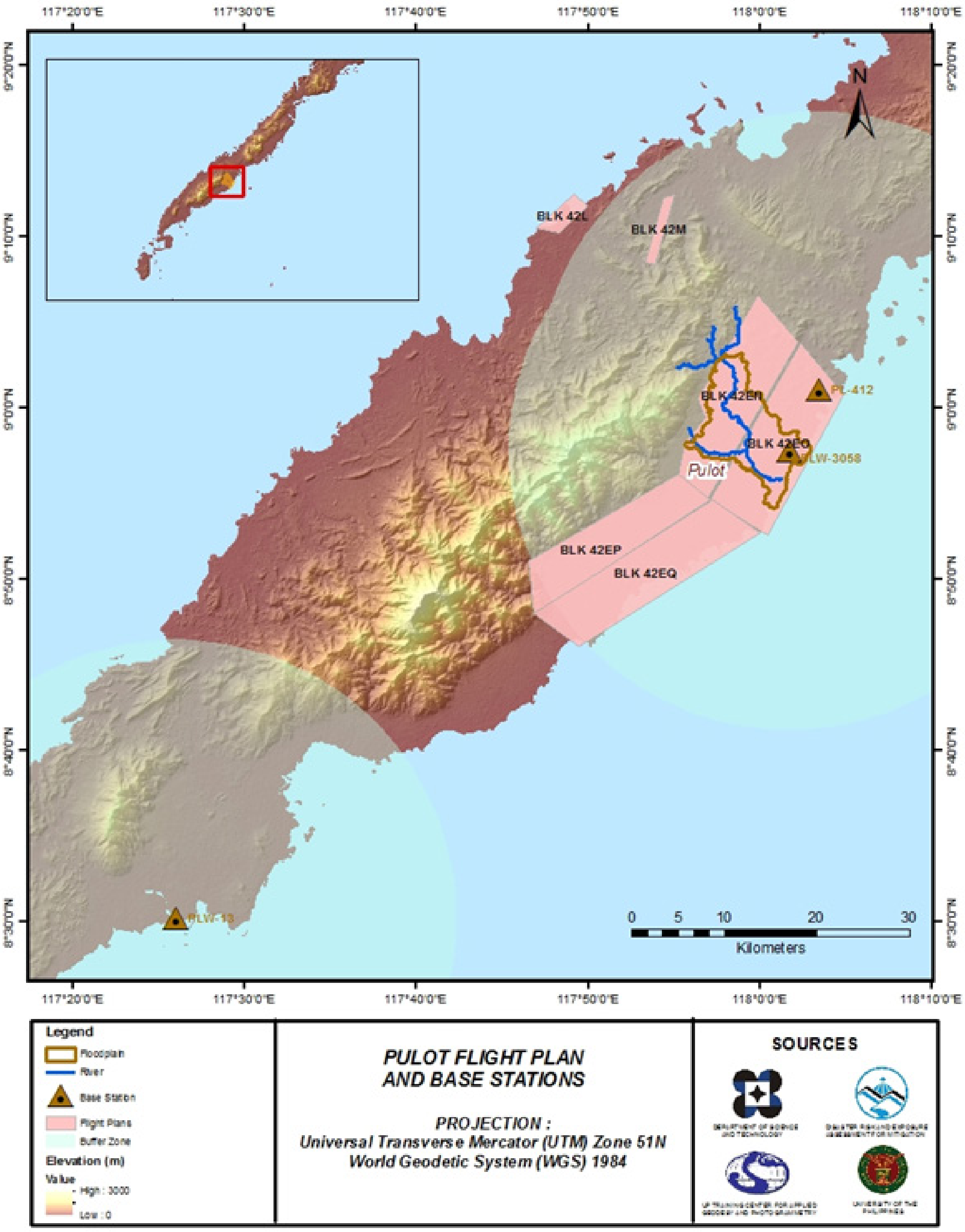

Figure 2. Flight plan and base stations used for Pulot Floodplain.

2.2 Ground Base Stations

The project team was able to recover one (1) NAMRIA ground control point, PLW-13, which is of second (2nd) order accuracy. The project team also recovered one (1) NAMRIA benchmark, PL-412 and one (1) ground control point, PLW-3058, which is of fourth (4th) order accuracy.The certification for the NAMRIA reference point is found in Annex 2 while the baseline processing reports for the benchmark and recoveredcontrol pointare found in Annex 3. These were used as base stations during flight operations for the entire duration of the survey (November 12 to December 12, 2015). Base stations were observed using dual frequency GPS receivers:TRIMBLE SPS 852 and TRIMBLE SPS 882. Flight plans and location of base stations used during the aerial LiDAR acquisition in Pulot Floodplain are shown in Figure 2.

Figure 3 and Figure 4 show the recovered NAMRIA reference points within the area. In addition, Table 2 to Table 4 show the details about the following NAMRIA control stations, while Table 5 lists all ground control points occupied during the acquisition together with the corresponding dates of utilization.

Figure 3. GPS set-up over PLW-13 at Barangay Rio Tuba, Palawan (a) and NAMRIA reference point PLW-13 (b) as recovered by the field team.

Table 2. Details of the recovered NAMRIA horizontal control point PLW-13 used as base station for the LiDAR acquisition.

Station Name	PLW-13	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 30' 17.42901" North 117° 25' 55.42672"East -0.25567 meters
Grid Coordinates, Philippine Transverse Mercator Zone 4 (PTM Zone 4 PRS 92	Easting Northing	382,414.126 meters 940,540.844 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 30'13.19373" North 117°26'0.86501" East 49.35 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984	Easting Northing	547,553.57 meters 940,076.76 meters

Table 3. Details of the recovered NAMRIA benchmarkPL-412 with processed coordinates used as base station for the LiDAR acquisition.

Station Name	PL-412	
Order of Accuracy	2nd	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	9° 01’ 08.45200” North 118° 03’ 21.49607” East -0.337 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	9° 01’ 04.14225” North 118° 03’ 26.88749” East 49.765 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	-44,042.610 meters 100,0578.048 meters

Figure 4. GPS set-up over PLW-3058on the ground inside Caranasan Elementary School, Española, Palawan (a) and NAMRIA reference point PLW-3058(b) as recovered by the field team.

Table 4. Details of the recovered NAMRIA horizontal control point ZGS-1 used as base station for the LiDAR data acquisition

Station Name	PLW-3058	
Order of Accuracy	4th	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude Longitude Ellipsoidal Height	8° 57’ 34.41144” North 118° 01’ 39.35193” East -2.979 meters
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude Longitude Ellipsoidal Height	8° 57’ 30.11418” North 118° 01’ 44.74872” East 47.176 meters
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N PRS 1992)	Easting Northing	-47,262.005 meters 994,023.989 meters

Table 5. Ground Control Points used during LiDAR data acquisition

Date Surveyed	Flight Number	Mission Name	Ground Control Points
December 5, 2015	3573G	2BLK42Ov339A	PL-412; PLW-3058
December 5, 2015	3575G	2BLK42OQ339B	PL-412; PLW-3058
December 7, 2015	3581G	2BLK42NPQ341A	PLW-13; PLW-3058
December 8, 2015	3585G	2BLK42Nv342A	PLW-13; PLW-3058
26 FEB 2016	23140P	1BLK76BS057A	ZGS-58 & ZGS-68

2.3 Flight Missions

Four (4) missions were conducted to complete the LiDAR data acquisition in Pulot floodplain, for a total of fifteen hours and twenty minutes (15+20) of flying time for RP-9022. The missions were acquired using the Gemini LiDAR system. Table 6 shows the total area of actual coverage and the corresponding flying hours of the mission while Table 7 presents the actual parameters used during the LiDAR data acquisition.

Table 6. Flight missions for LiDAR data acquisition in Pulot Floodplain

Date Sur-veyed	Flight Number	Flight Plan Area (km2)	Surveyed Area (km2)	Area Surveyed within the Floodplain (km2)	Area Surveyed Outside the Floodplain (km2)	No. of Images (Frames)	Flying Hours	
							Hr	Min
December 5, 2015	3573G	146.39	111.73	25.51	86.22	NA	3	53
December 5, 2015	3575G	258.32	147.76	21.54	126.22	NA	3	35
December 7, 2015	3581G	343.78	157.71	8.65	149.06	NA	3	59
December 8, 2015	3585G	115.80	112.13	42.34	69.79	NA	3	53
TOTAL	864.29	529.33	98.04	431.29	NA	15	20	29

Table 7. Actual parameters used during LiDAR data acquisition

Flight Number	Flying Height (m AGL)	Overlap (%)	FOV (θ)	PRF (khz)	Scan Frequency (Hz)	Average Speed (kts)	Average Turn Time (Minutes)
3573G	600/850	30	50	100/125	40	130	5
3575G	600/850	30	50	100/125	40	130	5
3581G	600/850/1000	30	26/50	100/125	40/50	130	5
3585G	500/600/700 /850/1000	30	30/40/50	100/125	40/50	130	5

2.4 Survey Coverage

Pulot Floodplain is located along the province of Palawan with majority of the floodplain situated within the municipality ofSofronioEspañola. The list of municipalities and cities surveyed, with at least one (1) square kilometer coverage, is shown in Table 8. The actual coverage of the LiDAR acquisition for Pulot Floodplain is presented in Figure 5.

Table 8. List of municipalities and cities surveyed during Pulot Floodplain LiDAR survey

Province	City/Municipality	Area of Munici-pality/ City (km2)	Total Area Surveyed (km2	Percentage of Area Surveyed
Palawan	Sofronio Española	477.5	202.03	42.31%
	Brooke’s Point	893.39	225.16	25.20%
	Quezon	917.97	21.32	2.32%
Total		2288.86	448.51	19.60%

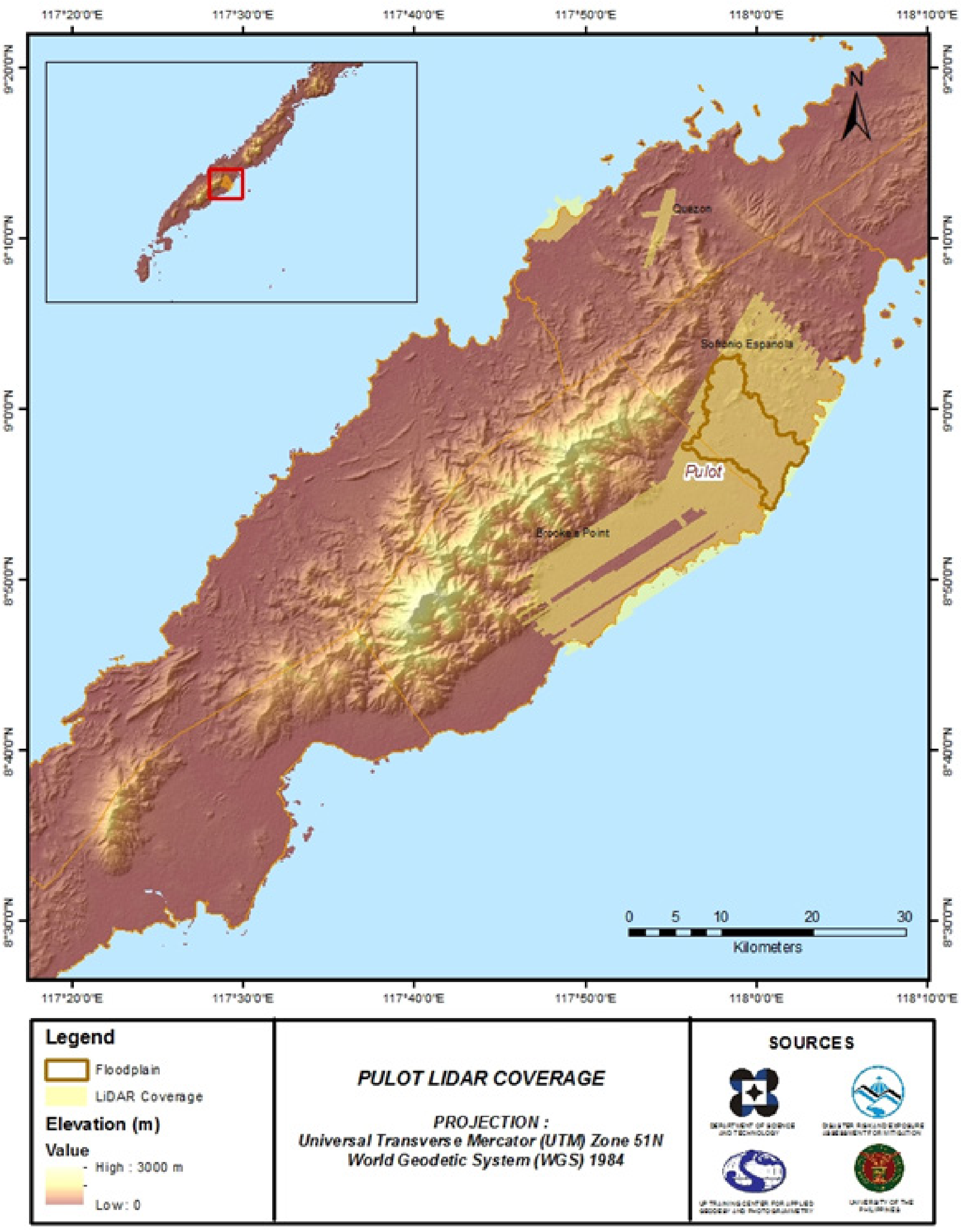

Figure 5. Actual LiDAR survey coverage for Pulot Floodplain.

CHAPTER 3: LIDAR DATA PROCESSING FOR PULOT FLOODPLAIN

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The methods applied in this chapter were based on the DREAM methods manual (Ang, et al., 2014) and further enhanced and updated in Paringit, et al. (2017).

3.1 Overview of the LIDAR Data Pre-Processing

The data transmitted by the Data Acquisition Component were checked for completeness based on the list of raw files required to proceed with the pre-processing of the LiDAR data. Upon acceptance of the LiDAR field data, georeferencing of the flight trajectory was done to obtain the exact location of the LiDAR sensor when the laser was shot.

Point cloud georectification was performed to incorporate correct position and orientation for each point acquired. The georectified LiDAR point clouds were subject for quality checking to ensure that the required accuracies of the program, which are the minimum point density, vertical and horizontal accuracies, are met. The point clouds were then classified into various classes before generating Digital Elevation Models such as Digital Terrain Model and Digital Surface Model.

Using the elevation of points gathered in the field, the LiDAR-derived digital models were calibrated. Portions of the river that are barely penetrated by the LiDAR system were replaced by the actual river geometry measured from the field by the Data Validation and Bathymetry Component. LiDAR acquired temporally were then mosaicked to completely cover the target river systems in the Philippines. Orthorectification of images acquired simultaneously with the LiDAR data was done through the help of the georectified point clouds and the metadata containing the time the image was captured.

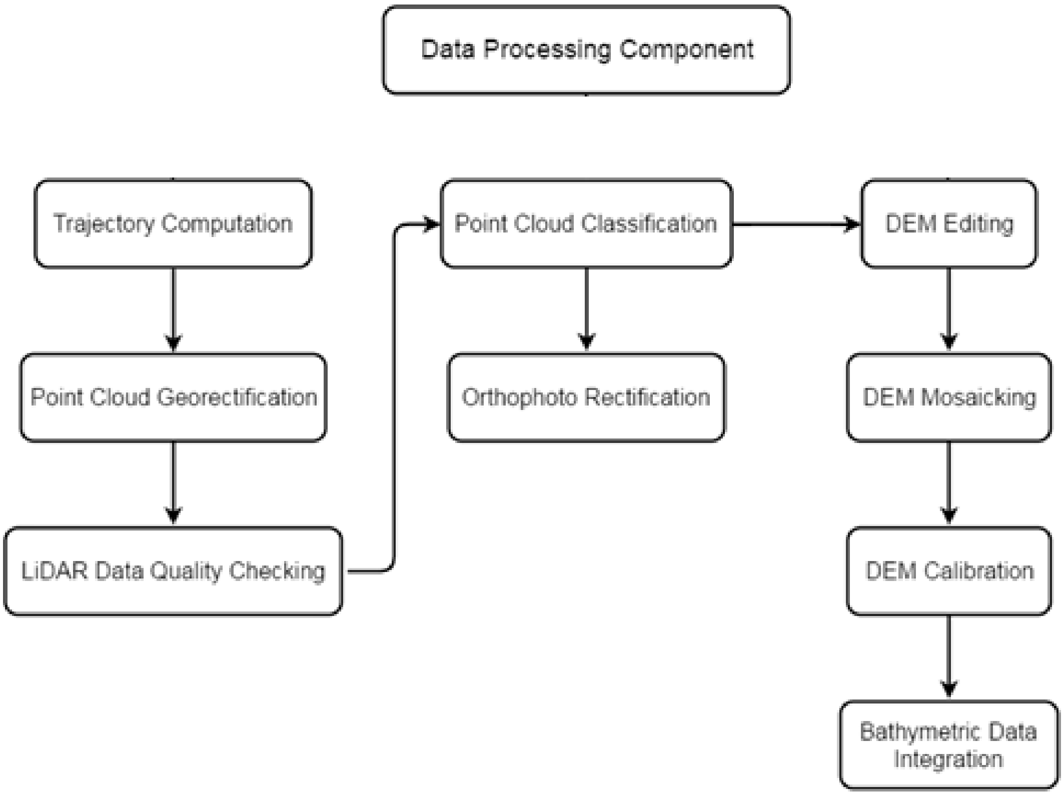


Figure 6. Schematic Diagram for Data Pre-Processing Component

3.2 Transmittal of Acquired LiDAR Data

Data transfer sheets for all the LiDAR missions for Pulot Floodplain can be found in Annex 5. Missions flown during the survey conducted on November 2015 used the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) Gemini system over Sofronio Espanola, Palawan. The Data Acquisition Component (DAC) transferred a total of 63.9 Gigabytes of Range data, 679 Megabytes of POS data, 25.94 Megabytes of GPS base station data, and no raw image data to the data server on November 26, 2015 for the survey. The Data Pre-processing Component (DPPC) verified the completeness of the transferred data. The whole dataset for Pulot was fully transferred on January 5, 2016, as indicated in the Data Transfer Sheets for Pulot Floodplain.

3.3 Trajectory Computation

The Smoothed Performance Metrics of the computed trajectory for flight 3573G, one of the Pulotflights, which is the North, East, and Down position RMSE values are shown in Figure 7. The x-axis corresponds to the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week, which on that week fell on November 26, 2015 00:00AM. The y-axis is the RMSE value for that particular position.

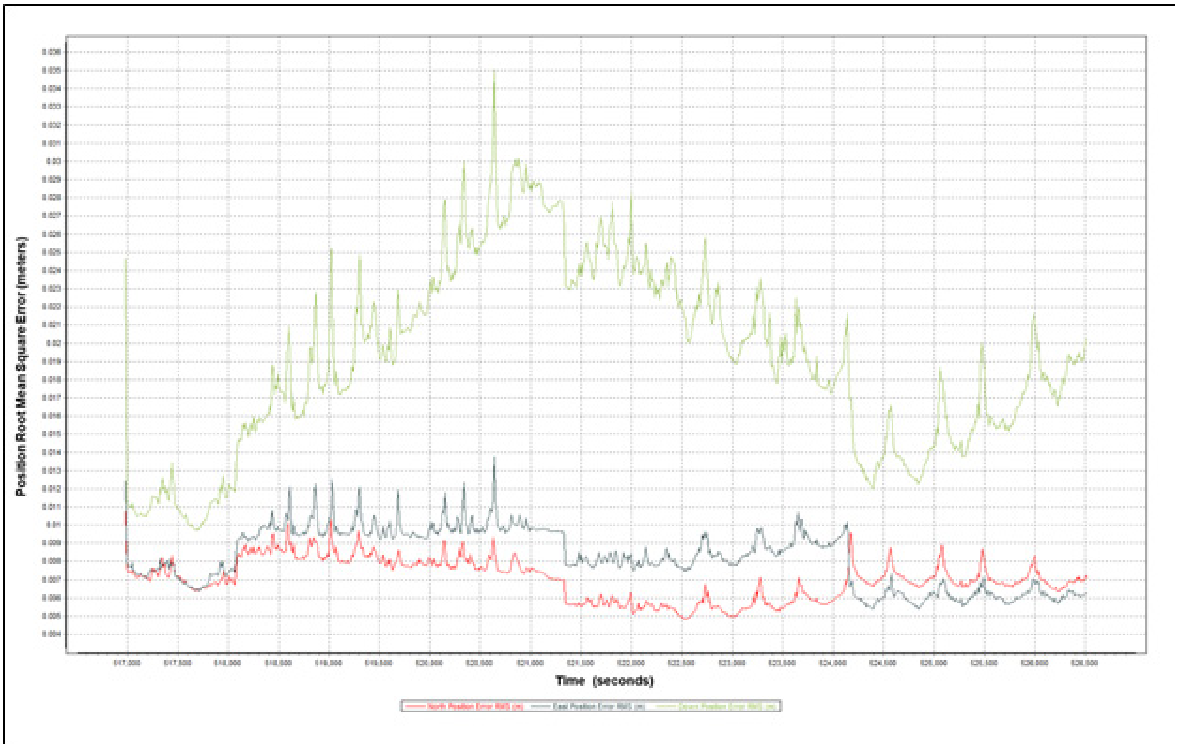


Figure 7. Smoothed Performance Metrics of a Pulot Flight 3573G.

The time of flight was from 517000 seconds to 526500 seconds, which corresponds to morning of November 26, 2015. The initial spike that is seen on the data corresponds to the time that the aircraft was getting into position to start the acquisition, and the POS system starts computing for the position and orientation of the aircraft. Redundant measurements from the POS system quickly minimized the RMSE value of the positions. The periodic increase in RMSE values from an otherwise smoothly curving RMSE values correspond to the turn-around period of the aircraft, when the aircraft makes a turn to start a new flight line. Figure 7 shows that the North position RMSE peaks at 1.04 centimeters, the East position RMSE peaks at 1.38 centimeters, and the Down position RMSE peaks at 3.50 centimeters, which are within the prescribed accuracies described in the methodology.

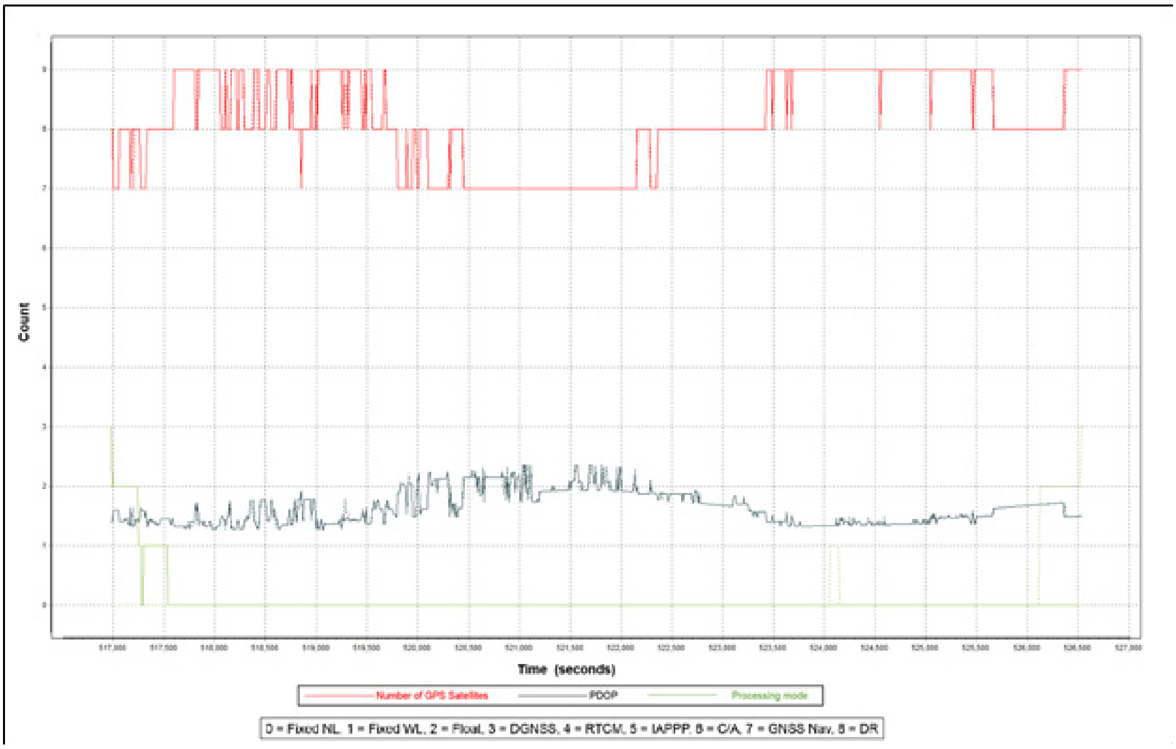


Figure 8. Solution Status Parameters of Pulot Flight 3573G.

The Solution Status parameters of flight 3573G, one of the Pulot flights, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used, are shown in Figure 8. The graphs indicate that the number of satellites during the acquisition did not go down to 6. Majority of the time, the number of satellites tracked was between 6 and 10. The PDOP value also did not go above the value of 3, which indicates optimal GPS geometry. The processing mode stayed at the value of 0 for majority of the survey with some peaks up to 1 attributed to the turns performed by the aircraft. The value of 0 corresponds to a Fixed, Narrow-Lane mode, which is the optimum carrier-cycle integer ambiguity resolution technique available for POSPAC MMS. All of the parameters adhered to the accuracy requirements for optimal trajectory solutions, as indicated in the methodology. The computed best estimated trajectory for all Pulot flights is shown in Figure 9.

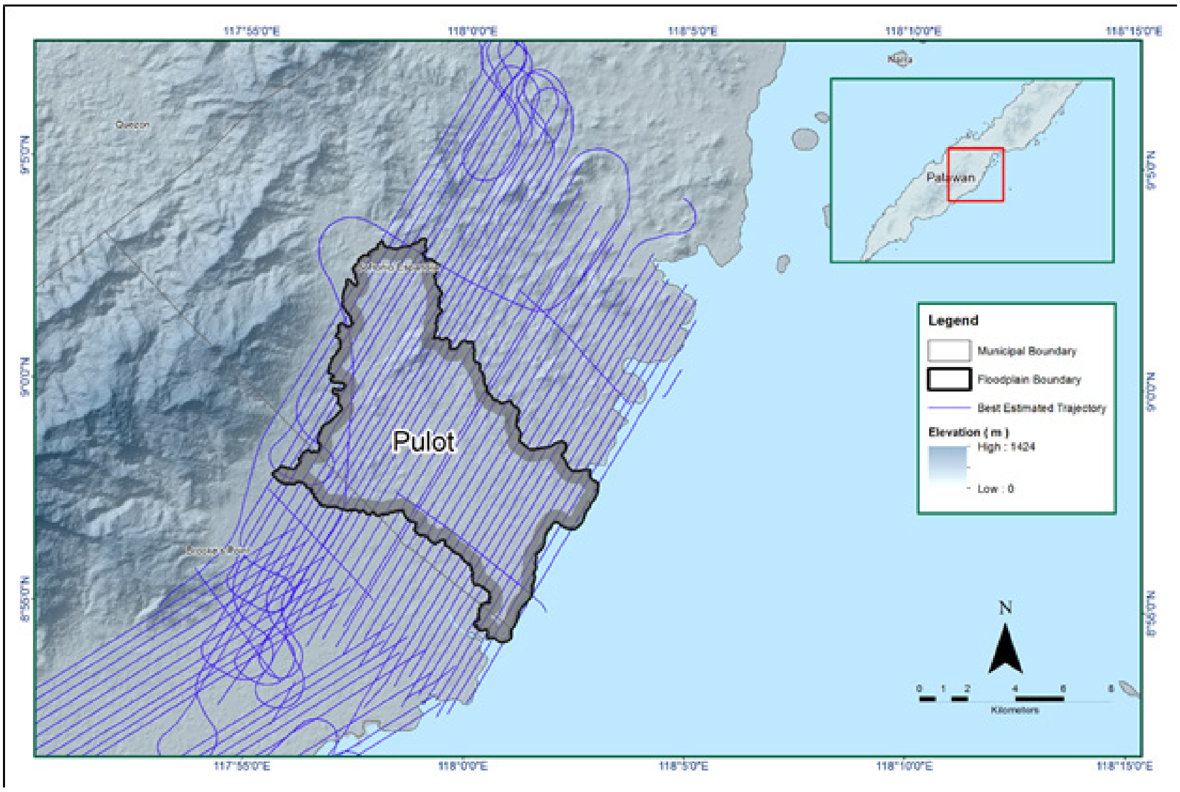


Figure 9. Best Estimated Trajectory for Pulot Floodplain.

3.4 LiDAR Point Cloud Computation

The produced LAS data contains 38flight lines, with each flight line containing one channel, since the Gemini system contains one channel only. The summary of the self-calibration results obtained from LiDAR processing in LiDAR Mapping Suite (LMS) software for all flights over Pulot Floodplain are given in Table 9.

Table 9. Self-Calibration Results values for Pulot flights.

Parameter	Computed Value
Boresight Correction stdev (<0.001degrees)	0.000283
IMU Attitude Correction Roll and Pitch Corrections stdev (<0.001degrees)	0.000976
GPS Position Z-correction stdev (<0.01meters)	0.0094

The optimum accuracy is obtained for all Pulot flights based on the computed standard deviations of the corrections of the orientation parameters. Standard deviation values for individual blocks are available in the Annex 8.

3.5 LiDAR Data Quality Checking

The boundary of the processed LiDAR data on top of a SAR Elevation Data over Pulot Floodplain is shown in Figure 10. The map shows gaps in the LiDAR coverage that are attributed to cloud coverage.

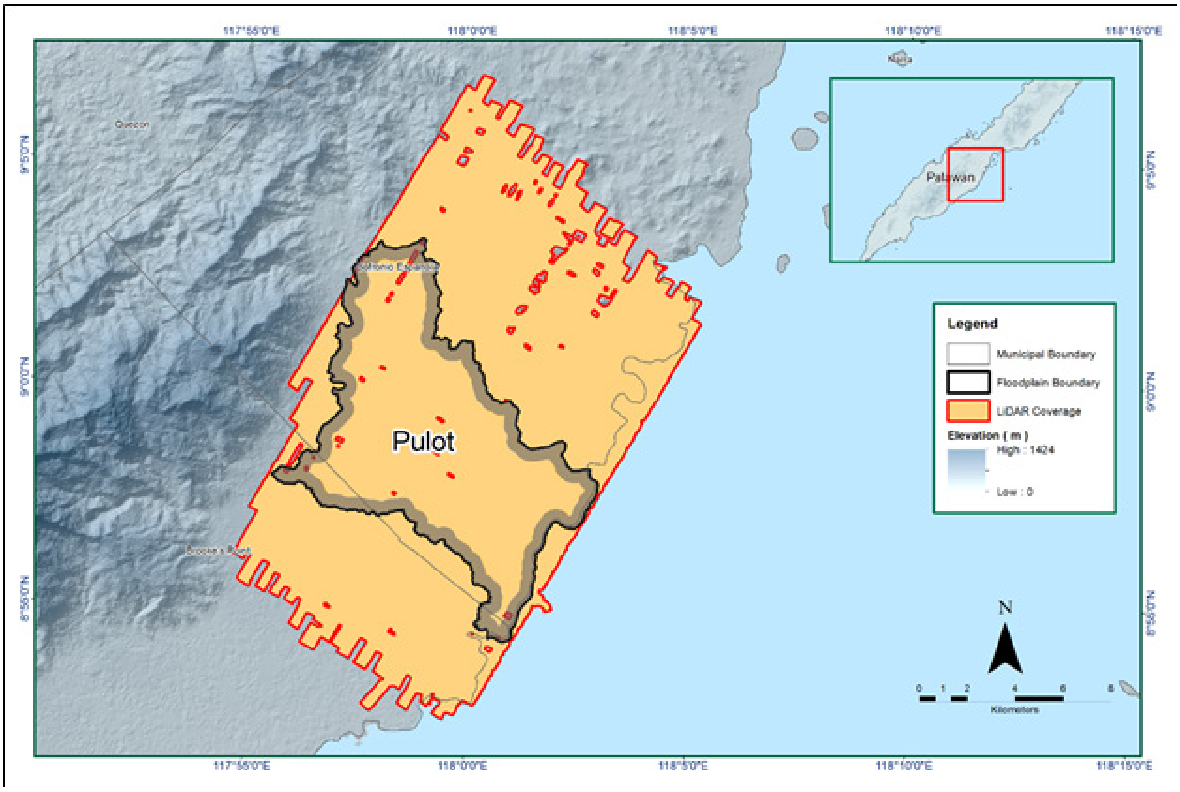


Figure 10. Boundary of the processed LiDAR data over Pulot Floodplain

Table 10. List of LiDAR blocks for Pulot Floodplain.

LiDAR Blocks	Flight Numbers	Area (sq km)
Palawan_reflights_Blk42eN	3573G	137.70
	3585G	
Palawan_reflights_Blk42eO	3573G	139.32
	3575G	
TOTAL		277.02 sq.km

The overlap data for the merged LiDAR blocks, showing the number of channels that pass through a particular location is shown in Figure 11. Since the Gemini system employs one channel, an average value of 1 (blue) for areas where there is limited overlap, and a value of 2 (yellow) or more (red) for areas with three or more overlapping flight lines are expected

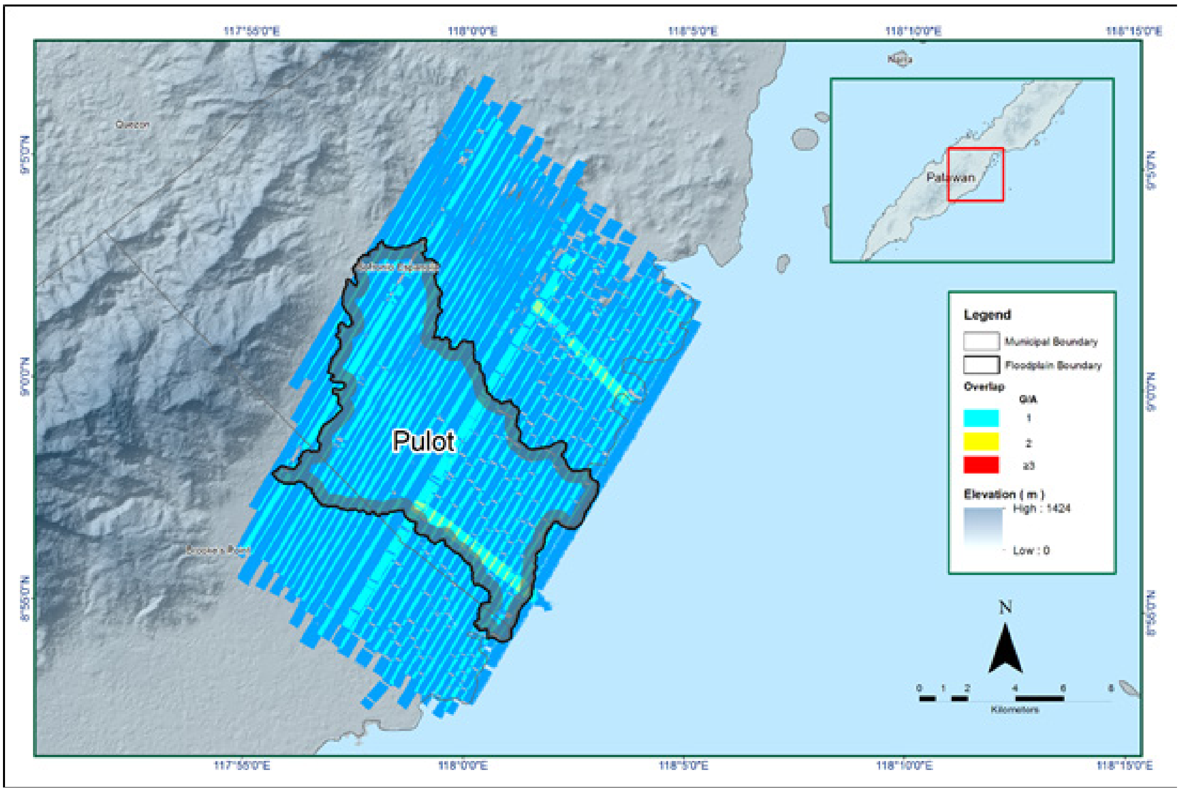


Figure 11. Image of data overlap for Pulot Floodplain.

The overlap statistics per block for the Pulot Floodplain can be found in Annex 8. One pixel corresponds to 25.0 square meters on the ground. For this area, the percent overlap is 30.43%, which passed the 25% requirement.

The pulse density map for the merged LiDAR data, with the red parts showing the portions of the data that satisfy the 2 points per square meter criterion is shown in Figure 12. It was determined that all LiDAR data for Pulot Floodplain satisfy the point density requirement, and the average density for the entire survey area is 5.87 points per square meter.

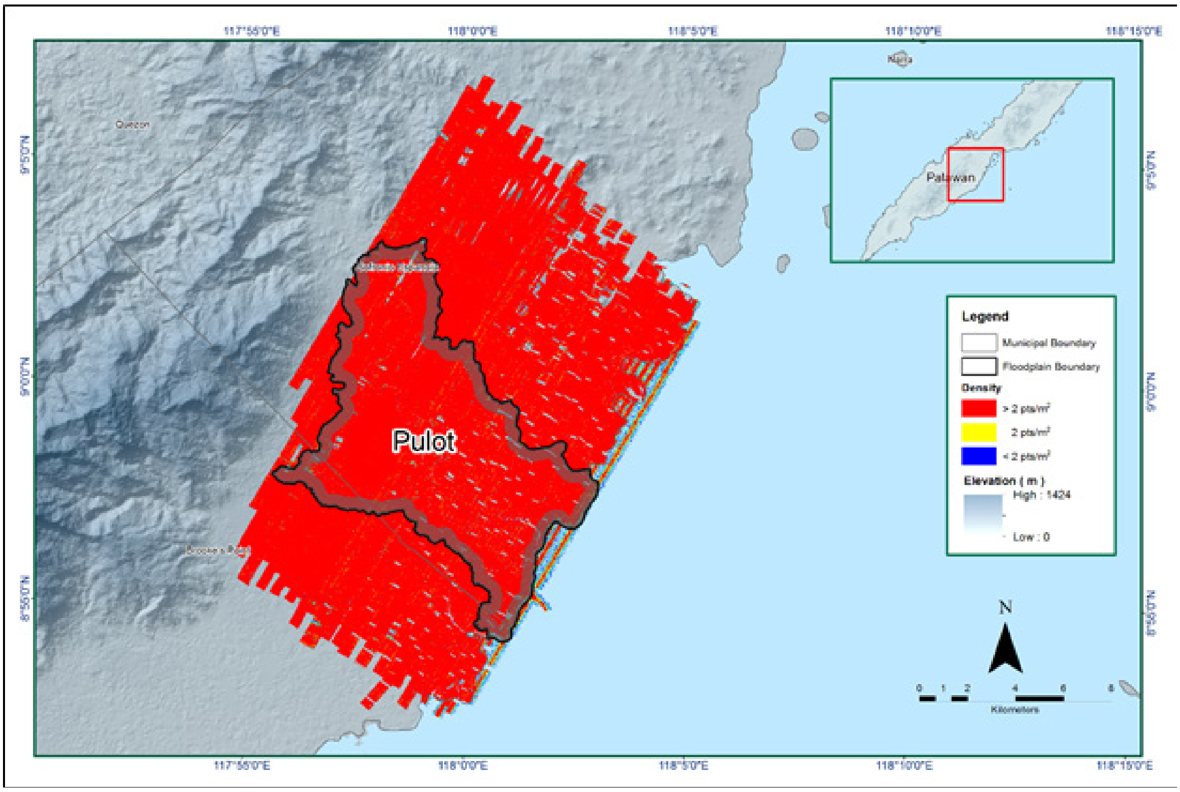


Figure 12. Pulse density map of merged LiDAR data for Pulot Floodplain

The elevation difference between overlaps of adjacent flight lines is shown in Figure 13. The default color range is from blue to red, where bright blue areas correspond to portions where elevations of a previous flight line, identified by its acquisition time, are higher by more than 0.20m relative to elevations of its adjacent flight line. Bright red areas indicate portions where elevations of a previous flight line are lower by more than 0.20m relative to elevations of its adjacent flight line. Areas with bright red or bright blue need to be investigated further using Quick Terrain Modeler software.

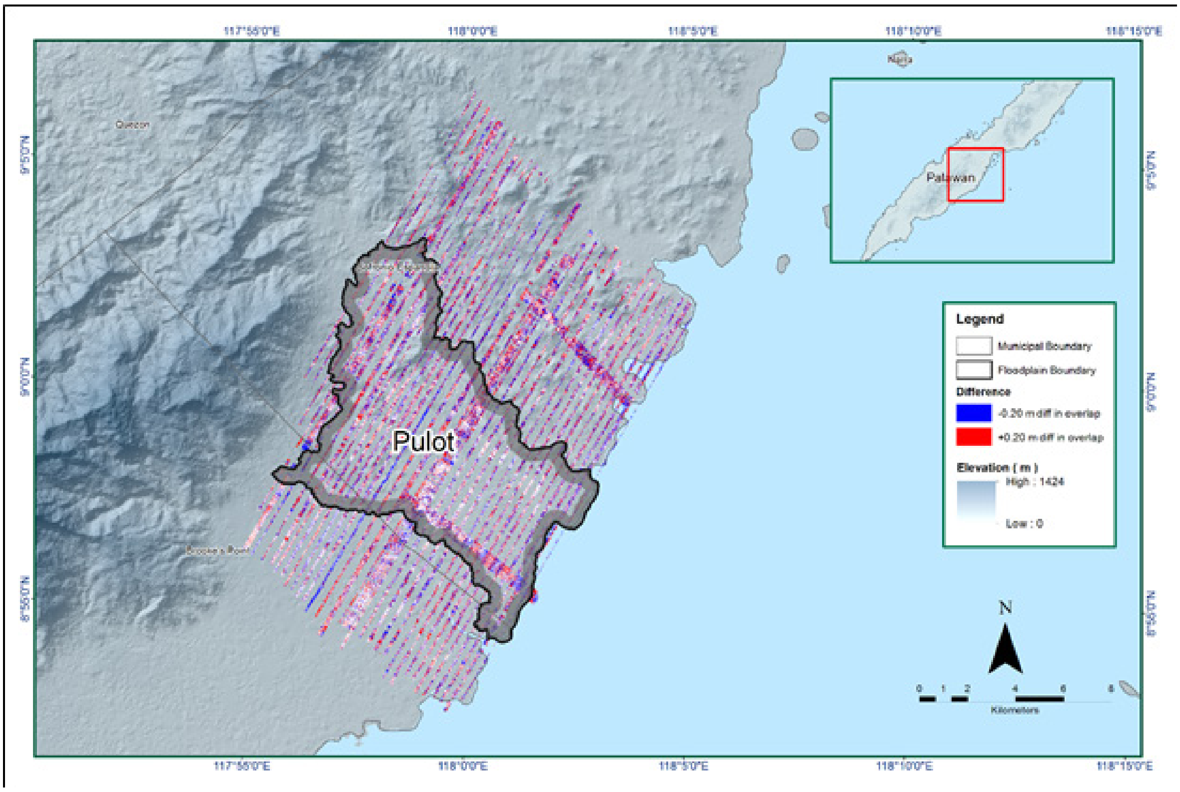


Figure 13. Elevation difference map between flight lines for Pulot Floodplain.

A screen capture of the processed LAS data from a Pulot flight 3573G loaded in QT Modeler is shown in Figure 14. The upper left image shows the elevations of the points from two overlapping flight strips traversed by the profile, illustrated by a dashed red line. The x-axis corresponds to the length of the profile. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. This profiling was repeated until the quality of the LiDAR data becomes satisfactory. No reprocessing was done for this LiDAR dataset.

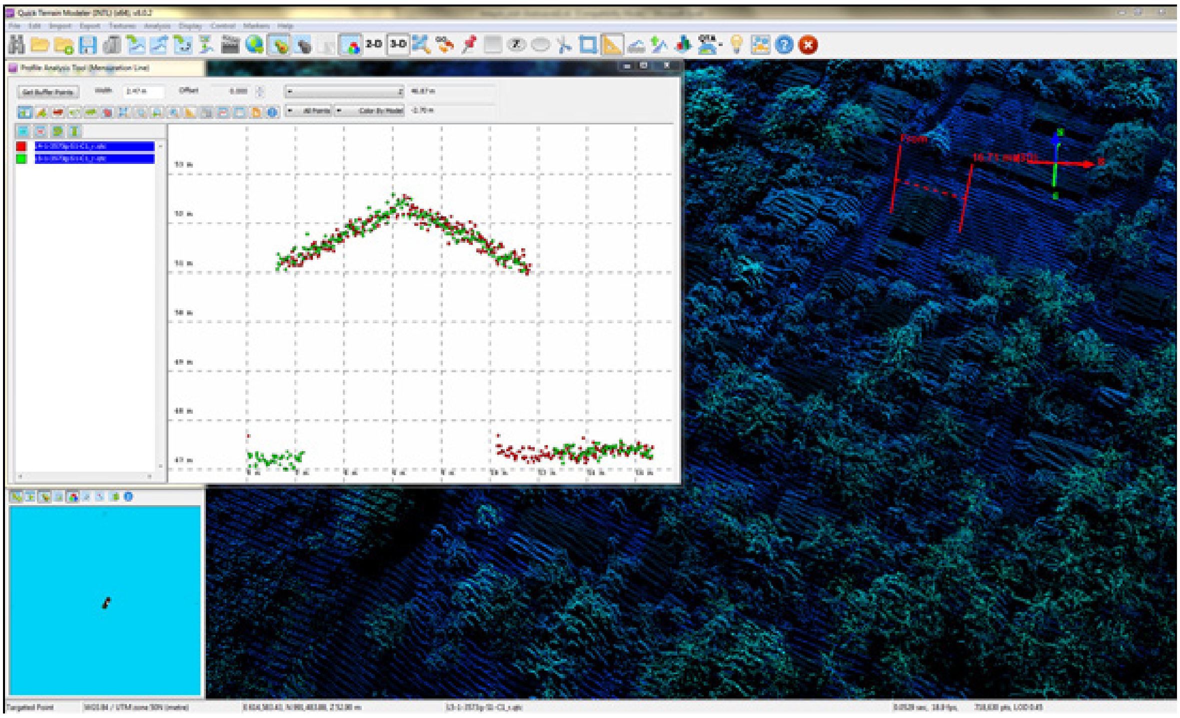


Figure 14. Quality checking for a Pulot flight 3573G using the Profile Tool of QT Modeler.

3.6 LiDAR Point Cloud Classification and Rasterization

Table 11. Pulot classification results in TerraScan.

Pertinent Class	Total Number of Points
Ground	112,876,688
Low Vegetation	129,875,848
Medium Vegetation	644,959,057
High Vegetation	680,955,102
Building	18,464,373

The tile system that TerraScan employed for the LiDAR data and the final classification image for a block in Pulot Floodplain is shown in Figure 15. A total of 374 1km by 1km tiles were produced. The number of points classified to the pertinent categories is illustrated in Table 11. The point cloud has a maximum and minimum height of 622.88 meters and 42.98 meters respectively.

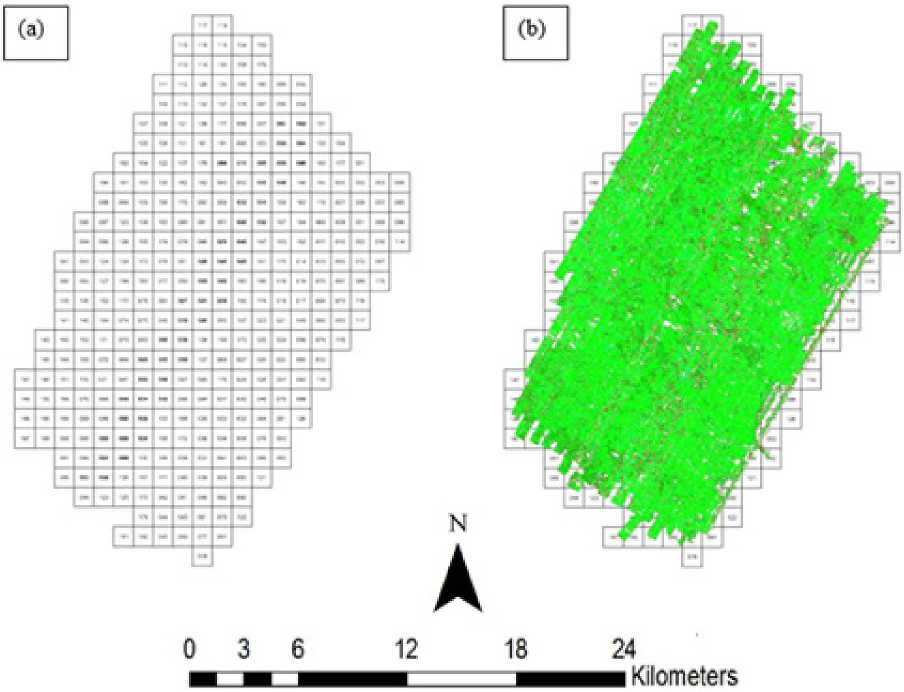


Figure 15. Tiles for Pulot floodplain (a) and classification results (b) in TerraScan

An isometric view of an area before and after running the classification routines is shown in Figure 16. The ground points are in orange, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

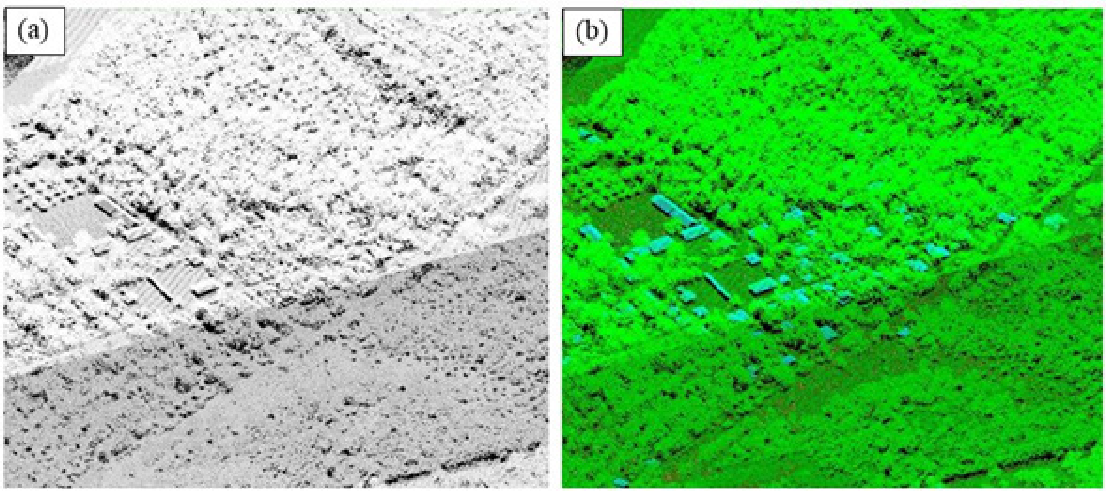


Figure 16. Point cloud before (a) and after (b) classification.

The production of last return (V_ASCII) and the secondary (T_ ASCII) DTM, first (S_ ASCII) and last (D_ ASCII) return DSM of the area in top view display are shown in Figure 17. It shows that DTMs are the representation of the bare earth while on the DSMs, all features are present such as buildings and vegetation.

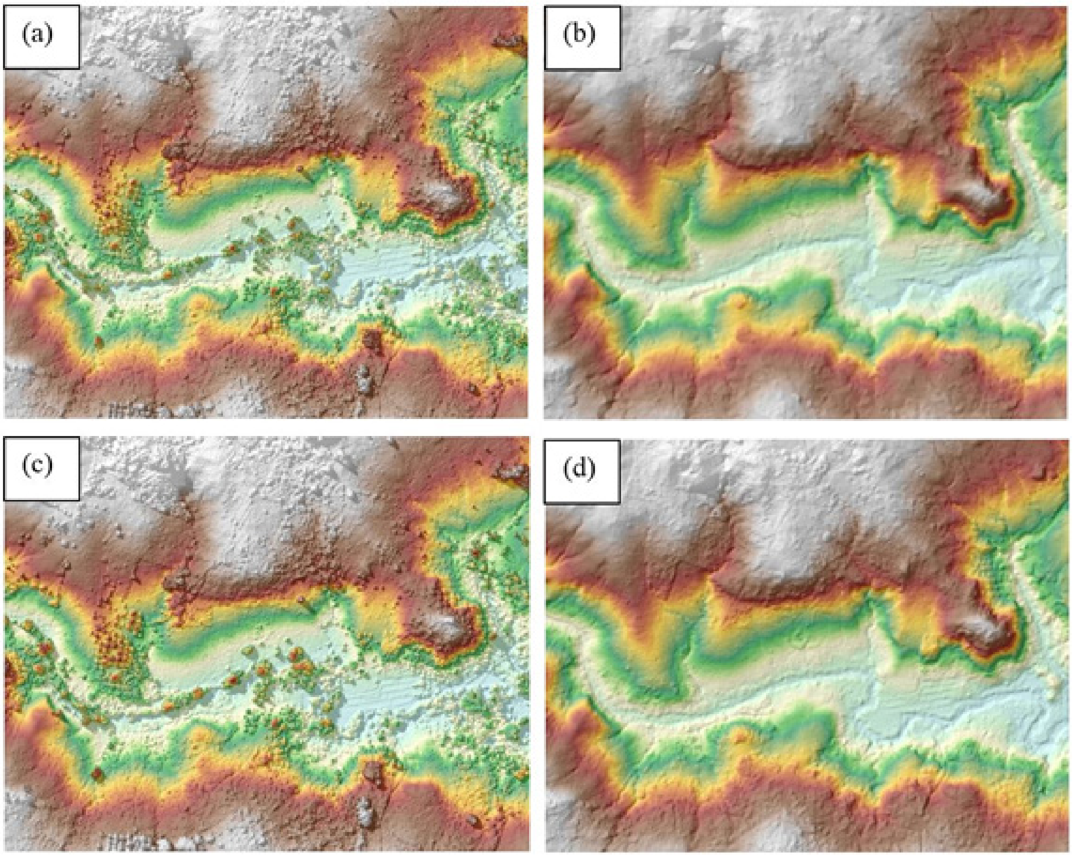


Figure 17. The production of last return DSM (a) and DTM (b), first return DSM (c) and secondary DTM (d) in some portion of Pulot Floodplain.

3.7 LiDAR Image Processing and Orthophotograph Rectification

There are no available orthophotographs for the Pulot floodplain.

3.8 DEM Editing and Hydro-Correction

Two (2) mission blocks were processed for Pulot Floodplain. These blocks are composed of Palawan_ reflight blocks with a total area of 277.02 square kilometers. Table B-4 shows the name and corresponding area of each block in square kilometers.

Table 12. LiDAR blocks with its corresponding area.

LiDAR Blocks	Area (sq km)
Palawan_reflights_Blk42eN	137.70
Palawan_reflights_Blk42eO	139.32
TOTAL	277.02 sq.km

Portions of DTM before and after manual editing are shown in Figure 18. The terrain (Figure 18a) was deformed and the feature has to be retrieved (Figure 18b) from the t ascii in order to correct the surface. A part of the profile of the waterway (Figure 18c) was elevated and has to be interpolated (Figure 18d) to allow the correct flow of water.

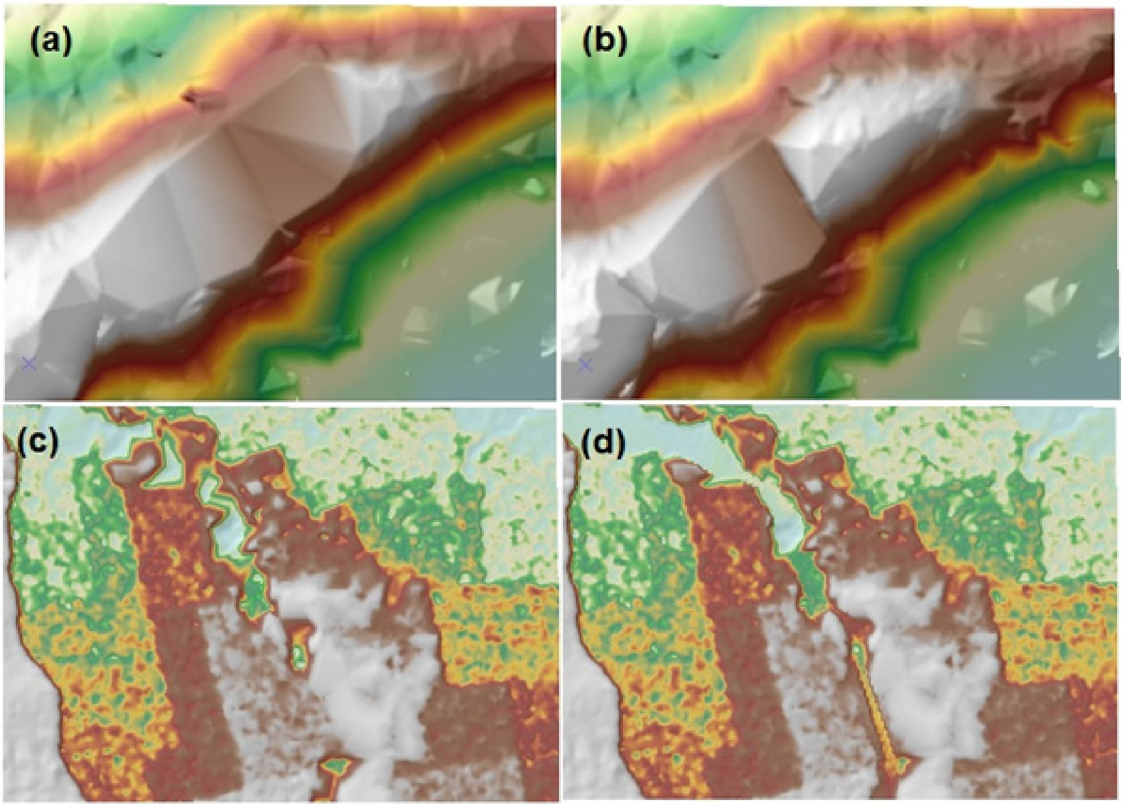


Figure 18. Portions in the DTM of Pulot floodplain – a flattened surface before (a) and after (b) object retrieval; an elevated part of the waterway before (a) and after (b) manual editing.

3.9 Mosaicking of Blocks

Palawan Block 42Aa was used as the reference block at the start of mosaicking because it was the first block mosaicked to the larger DTM of West Coast Palawan. Upon inspection of the blocks mosaicked for the Pulot floodplain, it was concluded that the elevation of the DTM for all of the blocks needed adjustment before merging

Mosaicked LiDAR DTM for Pulot Floodplain is shown in Figure 19. It can be seen that the entire Pulot Floodplain is 98. 49% covered by LiDAR data.

Table 13. Shift Values of each LiDAR Block of Pulot Floodplain

Mission Blocks	Shift Values (meters)		
	x	y	z
Palawan_reflights_Blk42eN	0.00	0.00	7.14
Palawan_reflights_Blk42eO	0.00	0.00	5.47

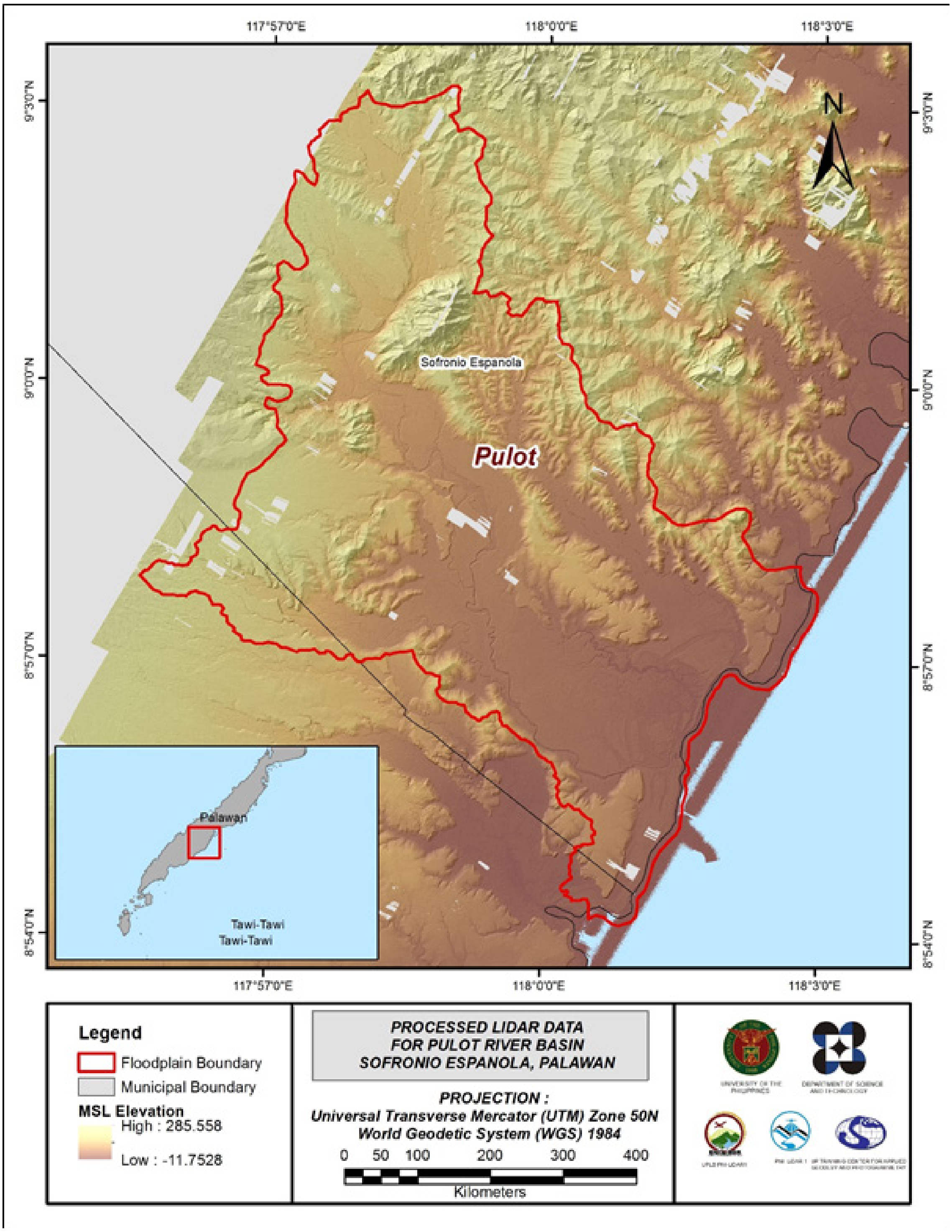


Figure 19. Map of Processed LiDAR Data for Pulot Floodplain.

3.10 Calibration and Validation of Mosaicked LiDAR Digital Elevation Model

The extent of the validation survey done by the Data Validation and Bathymetry Component (DVBC) in Pulot to collect points with which the LiDAR dataset was validated is shown in Figure 20. A total of 4,285 survey points were used for calibration and validation of Pulot LiDAR data. Random selection of 80% of the survey points, resulting in 3,328 points, were used for calibration.

A good correlation between the uncalibrated mosaicked LiDAR elevation values and the ground survey elevation values is shown in Figure 21. Statistical values were computed from extracted LiDAR values using the selected points to assess the quality of data and obtain the value for vertical adjustment. The computed height difference between the LiDAR DTM and calibration elevation values is 10.16 meters with a standard deviation of 0.20 meters. Calibration of Pulot LiDAR data was done by adding the height difference value, 10.16 meters, to Pulot mosaicked LiDAR data. Table 14 shows the statistical values of the compared elevation values between LiDAR data and calibration data.

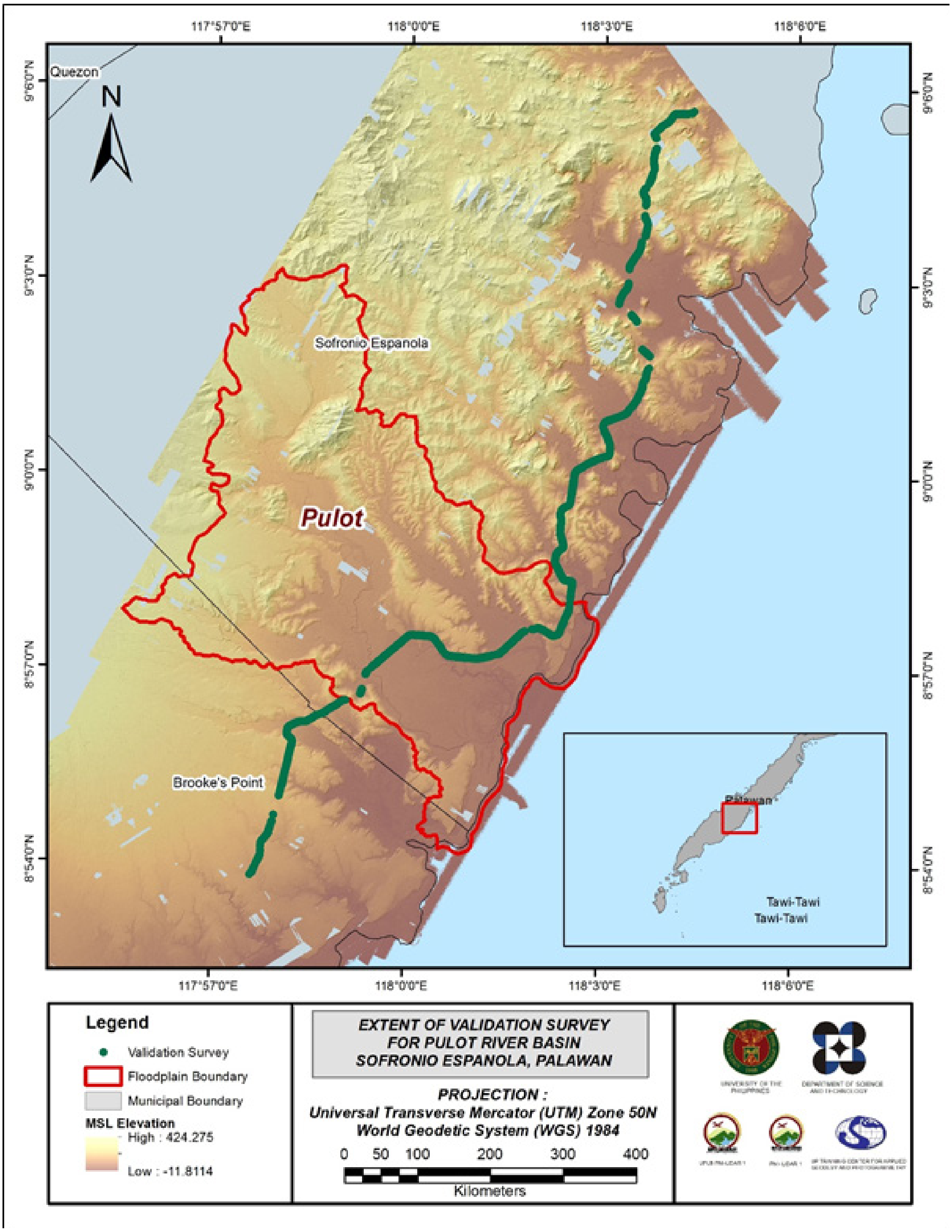


Figure 20. Map of Pulot Floodplain with validation survey points in green.

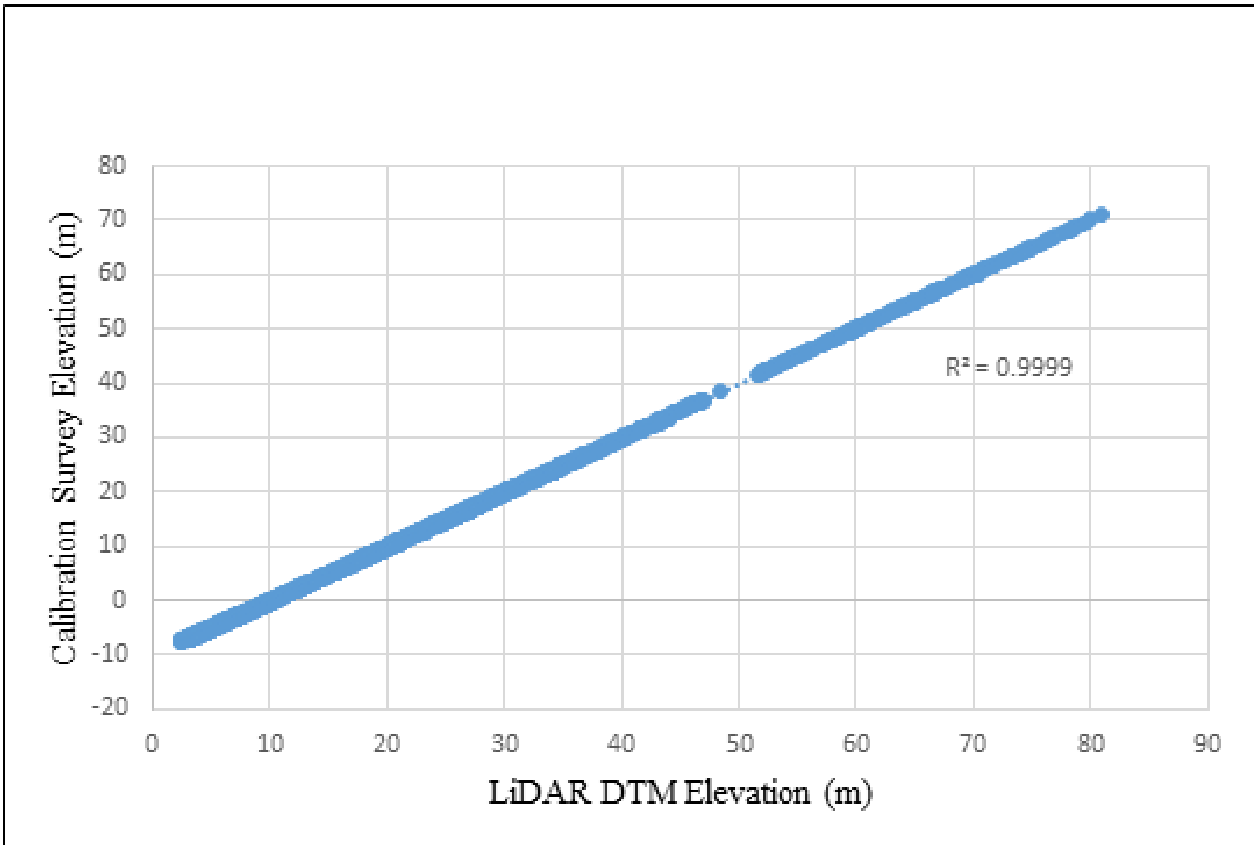


Figure 21. Correlation plot between calibration survey points and LiDAR data.

Table 14. Calibration statistical measures

Calibration Statistical Measures	Value (meters)
Height Difference	10.16
Standard Deviation	0.20
Average	10.16
Minimum	9.77
Maximum	10.55

The remaining 20% of the total survey points, resulting to 957 points, were used for the validation of calibrated Pulot DTM. A good correlation between the calibrated mosaicked LiDAR elevation values and the ground survey elevation, which reflects the quality of the LiDAR DTM is shown in Figure 22. The computed RMSE between the calibrated LiDAR DTM and validation elevation values is 0.20 meters with a standard deviation of 0.20 meters, as shown in Table 15.

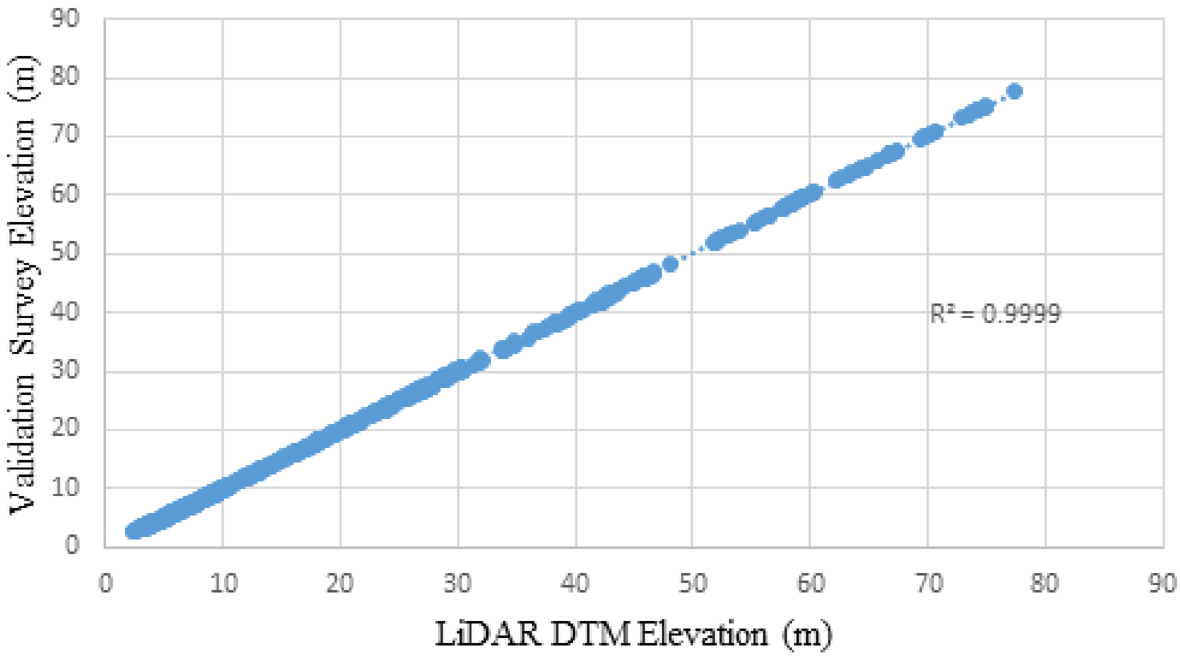


Figure 22. Correlation plot between validation survey points and LiDAR data.

Table 15. Calibration statistical measures

Calibration Statistical Measures	Value (meters)
RMSE	0.20
Standard Deviation	0.20
Average	-0.001
Minimum	-0.40
Maximum	0.40

3.11 Integration of Bathymetric Data into the LiDAR Digital Terrain Model

For bathy integration, cross section, zigzag and centerline data were available for Pulot with 6,263 bathymetric survey points. The resulting raster surface produced was done by Kernel Interpolation with Barrier method. After burning the bathymetric data to the calibrated DTM, assessment of the interpolated surface is represented by the computed RMSE value of 0.42 meters. The extent of the bathymetric survey done by the Data Validation and Bathymetry Component (DVBC) in Pulot integrated with the processed LiDAR DEM is shown in Figure 23.

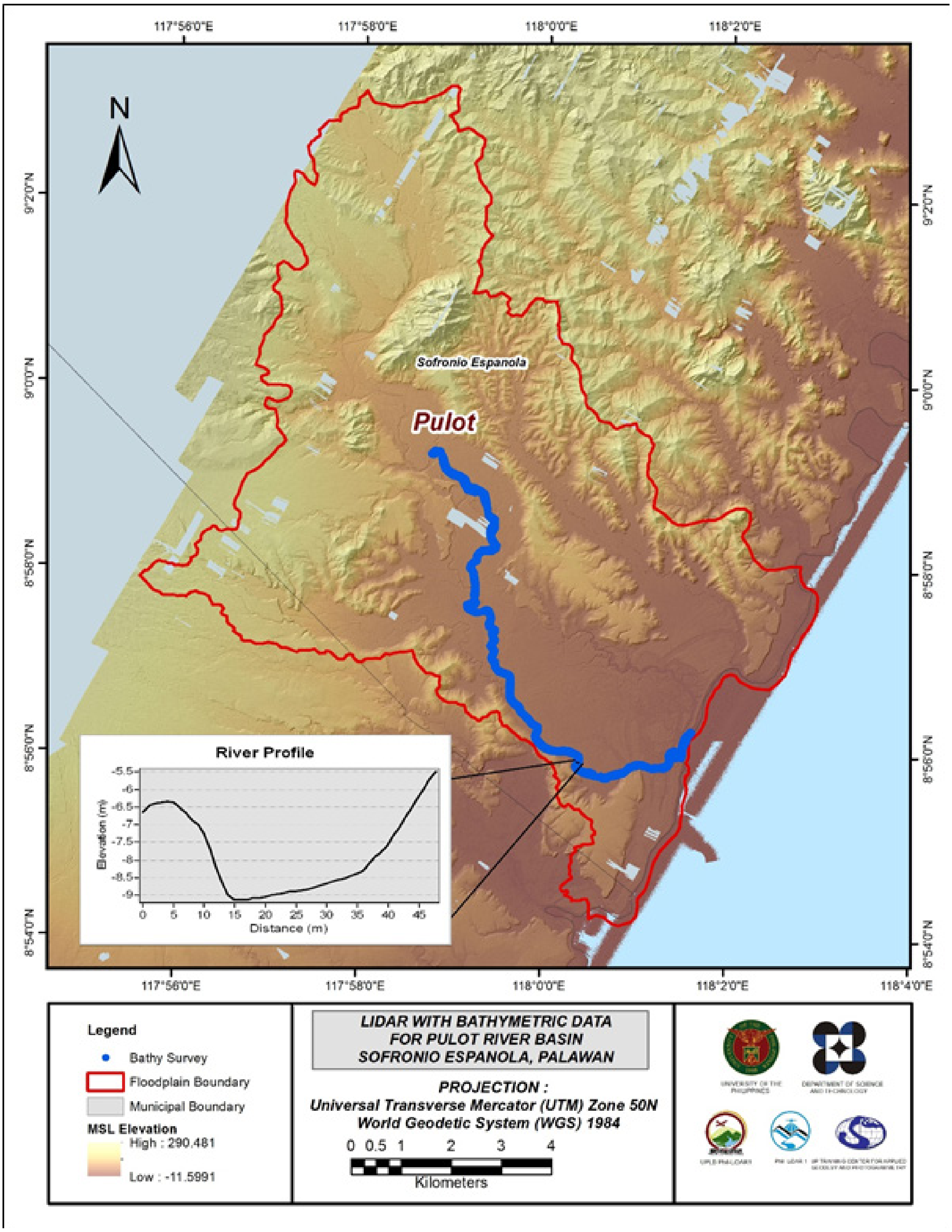


Figure 23. Map of Pulot Floodplain with bathymetric survey points shown in blue.

CHAPTER 4: LIDAR VALIDATION SURVEY AND MEASUREMENTS OF THE PULOT RIVER BASIN

Engr. Louie P. Balicanta, Engr. Joemarie S. Caballero, Ms. Patrizcia Mae. P. dela Cruz, and Engr. Dexter T. Lozano

The methods applied in this chapter were based on the DREAM methods manual (Balicanta et al., 2014) and further enhanced and updated in Paringit et al. (2017).

4.1 Summary of Activities

The AB Surveying and Development (ABSD) conducted a field survey in Pulot River on November 30, December 17 and 21, 2015, January 1 to 7 and 28, 2016 and February 1 to 8, 2016 with the following scope: cross-section, bridge as-built and water level marking in MSL of Pulot Bridge and bathymetric survey from the mouth of the river in Brgy. Pulot Shore to the upstream in Brgy. Iraray in the Municipality of Sofronio Española using GNSS survey technique, Hi-Target™ Echo Sounder and Nikon™ Total Station (DTM-332) Total Station. Random checking points for the contractor's cross-section and bathymetry data were gathered by DVC on August 16-28, 2016 using an Ohmex™ Single Beam Echo Sounder and Trimble® SPS 882 GNSS PPK survey technique. In addition to this, validation points acquisition survey was conducted covering the Pulot River Basin area. The entire survey extent is illustrated in Figure 24.

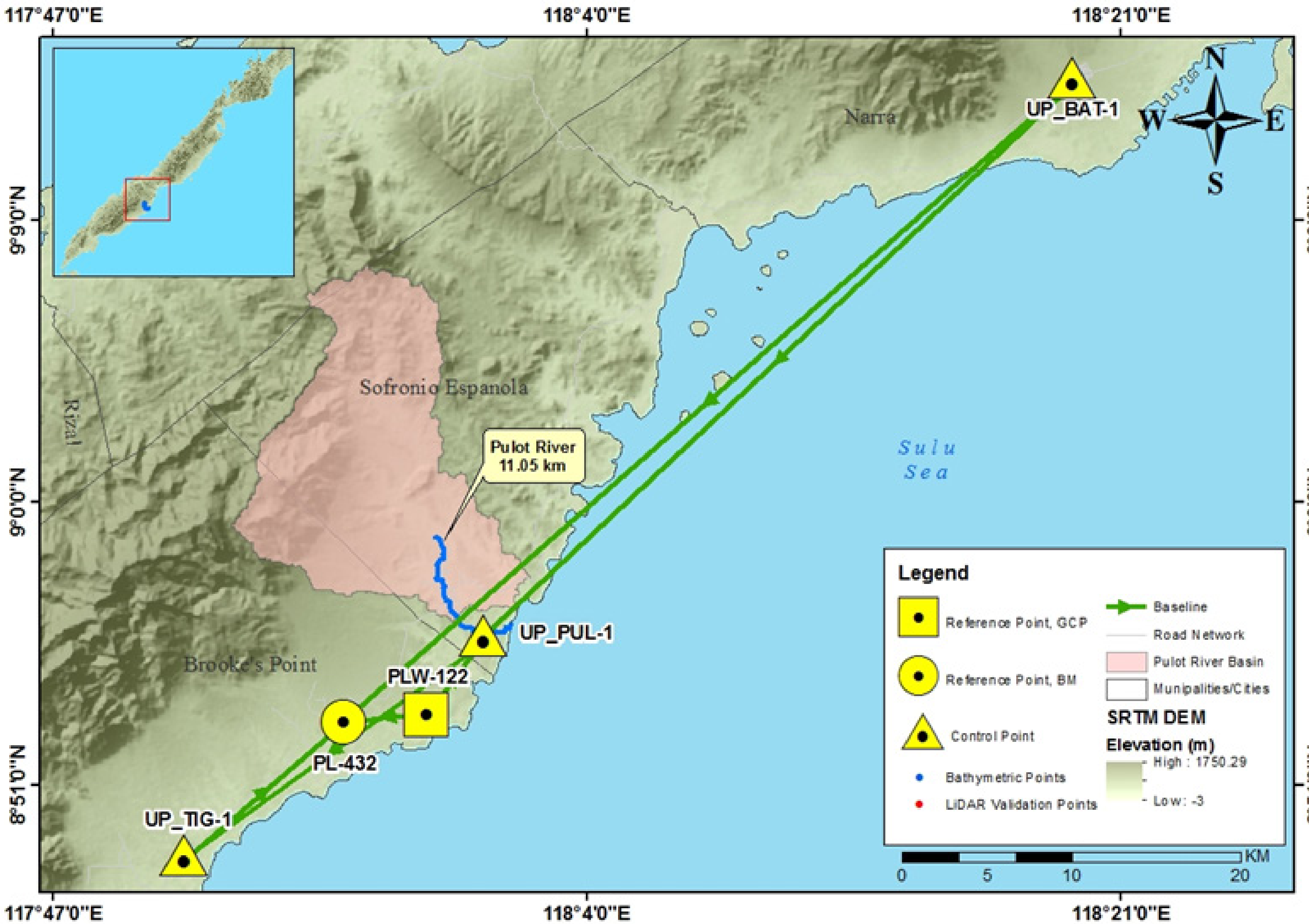


Figure 24. Extent of the bathymetric survey (in blue) in Pulot River and the LiDAR data validation (in red)

4.2 Control Survey

The GNSS network used for Pulot River is composed of two (2) loops established on August 23, 2016 occupying the following reference points: PLW-122, a second-order GCP, in Brgy. Calasaguen, Brookes Point, Palawan and PL-432, a first-order BM, in Brgy. Maasin, BrookesPoint, Palawan.

Three (3) control points established in the area by ABSD were also occupied: UP_BAT-1at the approach of Batang-batang Bridge in Brgy.Batang-batang, Narra, Province of Palawan, UP_PUL-1at the approach of Pulot Bridge in Brgy. Pulot Shore, Sofronio Española, Palawan, and UP_TIG-1located at the approach of TigaplanBridge in Brgy. Barong-barong, Brookes Point, Palawan.network established is illustrated in Figure 25.

Table 16. List of reference and control points used during the survey in Pulot River (Source: NAMRIA, UP-TCAGP)

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)				
		Latitude	Longitude	Ellipsoid Height (m)	BM Ortho (m)	Date Established
PLW-122	2nd order, GCP	8°53'15.04059"N	117°58'54.93380"E	62.283	0.061	2007
PL-432	1st order, BM	8°53'00.38663"N	117°56'15.64298"E	68.495	0.042	2008
UP_BAT-1	Established	9°13'36.17513"	118°19'28.44057"E	99.128	48.319	12-07-15
UP_PUL-1	Established	8°56'59.82715"N	117°59'27.45211"E	61.711	0.064	12-17-15
UP_TIG-1	Established	8°48'46.72587"N	117°51'10.83488"E	60.057	0.086	11-30-15

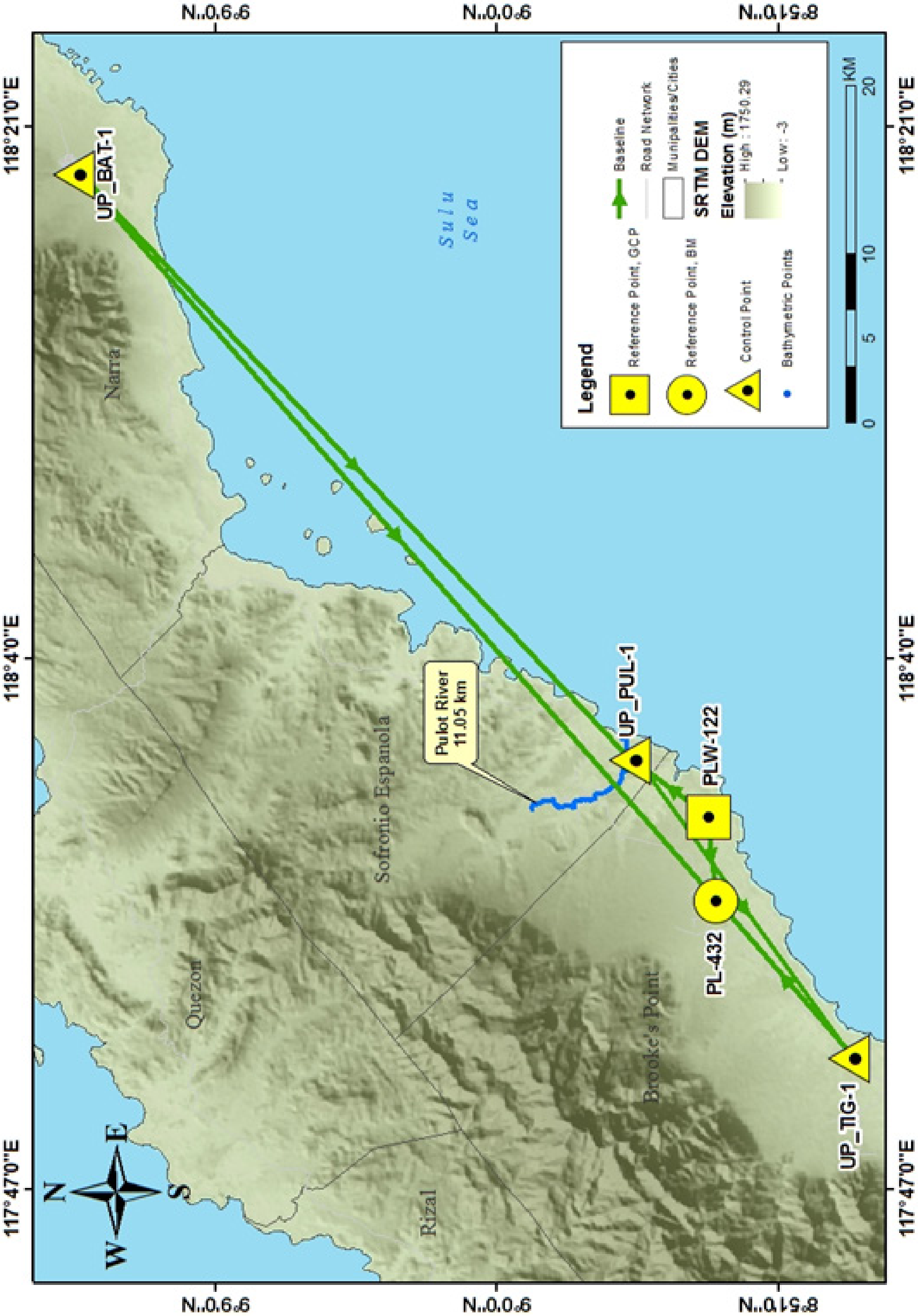


Figure 25. PulotRiver Basin Control Survey Extent

The GNSS set-ups on recovered reference points and established control points in Pulot River are shown from Figure 26 to Figure 30.

Figure 26. GNSS base set up, Trimble® SPS 852, at PLW-122, located in an open lot beside the house of Ms. Liza Jamili in Brgy. Calasaguen, Brookes Point, Province of Palawan.

Figure 27. GNSS receiver set up, Trimble® SPS 882, at PL-432, located at the approach of Maasin Bridge in Brgy. Maasin, Brookes Point, Province of Palawan

Figure 28. GNSS receiver set up, Trimble® SPS SPS 882, at UP_BAT-1, located near the approach of Batang-batang Bridge in Brgy. PrincesaUrduja, Narra, Province of Palawan

Figure 29. GNSS receiver set up, Trimble® SPS 985, at UP_PUL-1, located at the approach ofPulot Bridge, In Brgy. Pulot Shore, Sofronio Española, Province of Palawan

Figure 30. GNSS receiver set up, Trimble® SPS 985, at UP_TIG-1, located at the approach of Tigaplan Bridge in Brgy. Tigaplan, Brookes Point, Province of Palawan.

4.3 Baseline Processing

GNSS Baselines were processed simultaneously in TBC by observing that all baselines have fixed solutions with horizontal and vertical precisions within +/- 20 cm and +/- 10 cm requirement, respectively. In case where one or more baselines did not meet all of these criteria, masking was performed. Masking is done by removing/masking portions of these baseline data using the same processing software. It is repeatedly processed until all baseline requirements are met. If the reiteration yields out of the required accuracy, resurvey is initiated. Baseline processing result of control points in Pulot River Basin is summarized in Table 21 generated by TBC software.

Table 17. Baseline Processing Report for Pulot River Static Survey

Observation	Date of Observation	Solution Type	H. Prec. (Meter)	V. Prec. (Meter)	Geodetic Az.	Ellipsoid Dist. (Meter)	ΔHeight (Meter)
UP_PUL-1 --- UP_BAT-1	8-23-2016	Fixed	0.034	0.034	230°10'32"	27770.125	-37.471
PL-432 --- UP_BAT-1	8-23-2016	Fixed	0.024	0.024	228°16'42"	57014.957	-30.624
UP_TIG-1 --- UP_PUL-1	8-23-2016	Fixed	0.019	0.019	45°02'06"	21441.510	1.686
UP_TIG-1 --- PL-432	8-23-2016	Fixed	0.026	0.026	50°04'25"	12144.165	8.381
PLW-122 --- UP_PUL-1	8-23-2016	Fixed	0.012	0.012	8°11'07"	6977.113	-0.582
PLW-122 --- PL-432	8-23-2016	Fixed	0.020	0.020	264°43'06"	4887.669	6.201

As shown in Table 21 a total of six (6) baselines were processed with coordinate and ellipsoidal height values of PLW-122 held fixed. All of them passed the required accuracy.

4.4 Network Adjustment

After the baseline processing procedure, network adjustment was performed using TBC. Looking at the Adjusted Grid Coordinates table of the TBC generated Network Adjustment Report, it is observed that the square root of the squares of x and y must be less than 20 cm and z less than 10 cm in equation form:
$\sqrt{((x_e)^2 + (y_e)^2)} < 20$ cm and z_e <10 cm

Where:

x_e is the Easting Error,
$y_e$is the Northing Error, and
$z_e$is the Elevation Error

for each control point. See the Network Adjustment Report shown from Table 18 to Table 20 for the complete details. Refer to Appendix C for the computation for the accuracy of ABSD.

The five (5) control points, PL-432, PLW-122, UP-BAT-1, UP_PUL-1, and UP-TIG-1 were occupied and observed simultaneously to form a GNSS loop. The coordinates and ellipsoidal height of PLW-122 were held fixed during the processing of the control points as presented in Table 20. Through this reference point, the coordinates and ellipsoidal height of the unknown control points will be computed

Table 18. Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
PLW-122	Global	Fixed	Fixed		
UP_BAT-1	Grid				Fixed
UP_BAT-1	Global	Fixed	Fixed		
Fixed = 0.000001(Meter)					

Table 19. Adjusted Grid Coordinates

Point ID	Easting (meter)	Easting Error (meter)	Northing (meter)	Northing Error (meter)	Elevation (meter)	Elevation Error (meter)	Constratint
PLW-122	607965.609	?	982558.716	?	11.971	0.061	LL
PL-432	603101.186	0.014	982096.040	0.014	18.317	0.042	
UP_BAT-1	645509.020	?	1020187.067	?	48.319	?	LLe
UP_PUL-1	608940.379	0.010	989465.589	0.008	11.454	0.064	
UP_TIG-1	593808.679	0.017	974282.799	0.017	10.210	0.086	

With the mentioned equation, $\sqrt{((x\_e)^2+(y\_e)^2)}<20cm$ for horizontal and z_e<10 cm for the vertical; the computation for the accuracy are as follows:

PLW-122

horizontal accuracy	=	Fixed
vertical accuracy	=	Fixed

PL-432

horizontal accuracy	=	$\sqrt{((1.4)^2 + (1.4)^2}$
	=	$\sqrt{(1.96 + 1.96)}$
	=	1.98< 20 cm
vertical accuracy	=	4.2 < 10 cm

UP_BAT-1

horizontal accuracy = Fixed

vertical accuracy = Fixed

UP_PUL-1

horizontal accuracy = $\sqrt{((1.0)^2 + (0.8)^2}$

= $\sqrt{(1.0 + 0.64)}$

= 1.28< 20 cm

vertical accuracy = 6.4< 10 cm

UP_TIG-1

horizontal accuracy = $\sqrt{((1.7)^2 + (1.7)^2}$

= $\sqrt{(2.89 + 2.89)}$

= 2.40< 20 cm

vertical accuracy = 8.6< 10 cm

Following the given formula, the horizontal and vertical accuracy result of the four (4) occupied control points are within the required precision.

Table 20. Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
PLW-122	N8°53'15.04059"	E117°58'54.93380"	62.283	0.061	LL
PL-432	N8°53'00.38663"	E117°56'15.64298"	68.495	0.042	
UP_BAT-1	N9°13'36.17513"	E118°19'28.44057"	99.128	?	LLe
UP_PUL-1	N8°56'59.82715"	E117°59'27.45211"	61.711	0.064	
UP_TIG-1	N8°48'46.72587"	E117°51'10.83488"	60.057	0.086	

The corresponding geodetic coordinates of the observed points are within the required accuracy as shown in Table 20. Based on the result of the computation, the equation is satisfied; hence, the required accuracy for the program was met.

The summary of reference control points used is indicated in Table 21.

Table 21. Reference and control points used and its location

Control Point	Order of Accuracy	Geographic Coordinates (WGS 84)			UTM ZONE 51 N		
		Latitude	Longitude	Ellipsoidal Height (m)	Northing (m)	Easting (m)	BM Ortho (m)
PLW-122	2nd order, GCP	N8°53'15.04059"	E117°58'54.93380"	85.647	982558.716	607965.609	0.061
PL-432	1st order, BM	N8°53'00.38663"	E117°56'15.64298"	63.739	982096.040	603101.186	0.042
UP_BAT-1	Established	N9°13'36.17513"	E118°19'28.44057"	48.751	1020187.067	645509.020	48.319
UP_PUL-1	Established	N8°56'59.82715"	E117°59'27.45211"	52.045	989465.589	608940.379	0.064
UP_TIG-1	Established	N8°48'46.72587"	E117°51'10.83488"	48.192	974282.799	593808.679	0.086

4.5 Cross-section and Bridge As-Built Survey and Water Level Marking

Cross-section and as-built surveys were conducted on November 30, 2015 at the upstream side of Pulot Bridge in Brgy. Pulot Shore, Municipality Sofronio Española as shown in Figure 31. A Nikon® Total Station (DTM-332) was utilized for this survey as shown in Figure 32.

Figure 31. Downstream side of Pulot Bridge

Figure 32. As-built survey of Pulot Bridge

The cross-sectional line of Pulot Bridge is about 142.361 mwith thirty-two (32)cross-sectional points using the control pointsUP_PUL-1 and UP_PUL-2 as the GNSS base stations. The location map, cross-section diagram, and the bridge data form are shown in Figure 33 to Figure 35. No bridge checking points were gathered for Pulot River as it was impossible to conduct bridge cross-section checking on August 23, 2016 due tothe strong river current caused by heavy rains brought by the southwest monsoon.

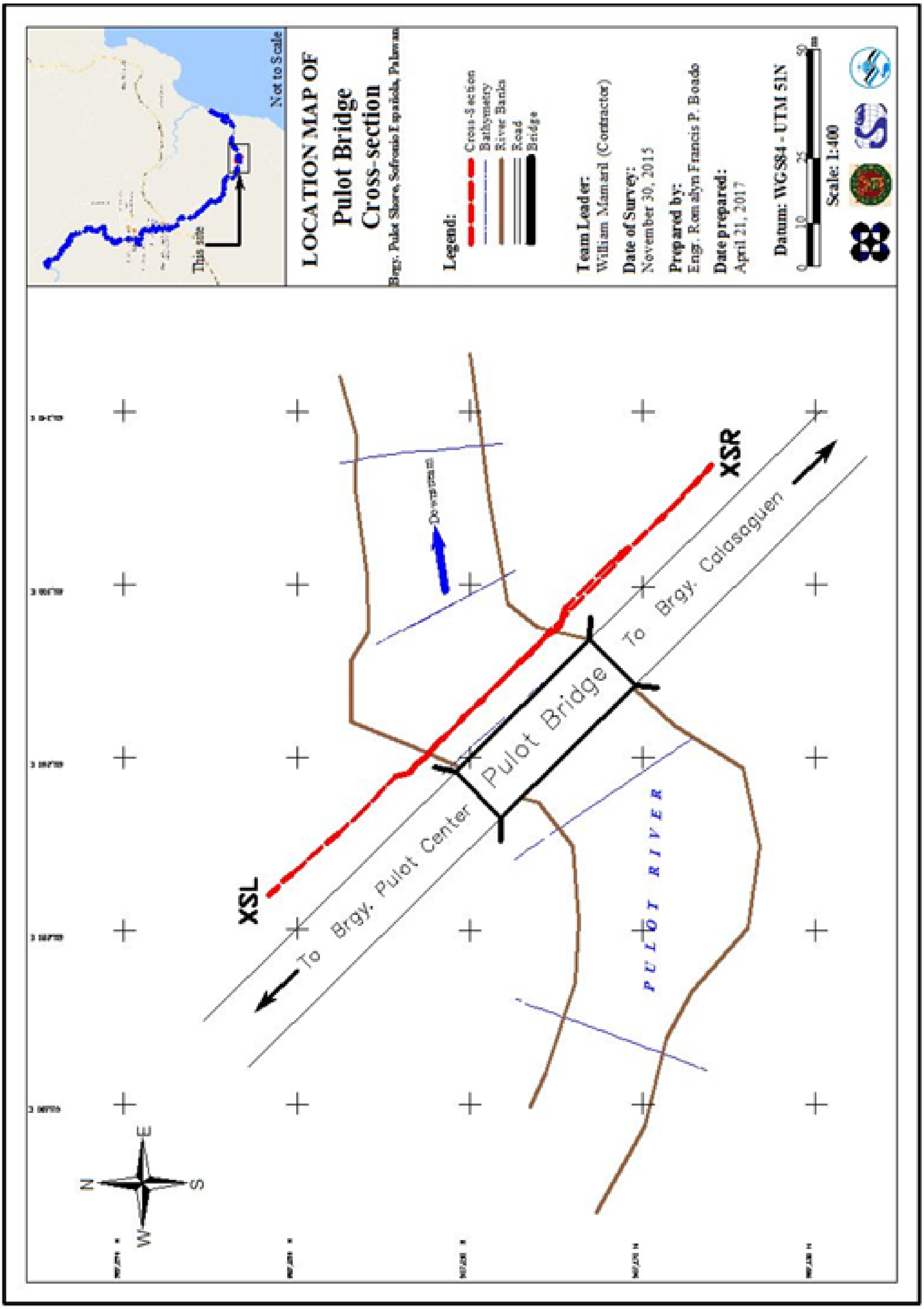


Figure 33. Pulot Bridge Location Map

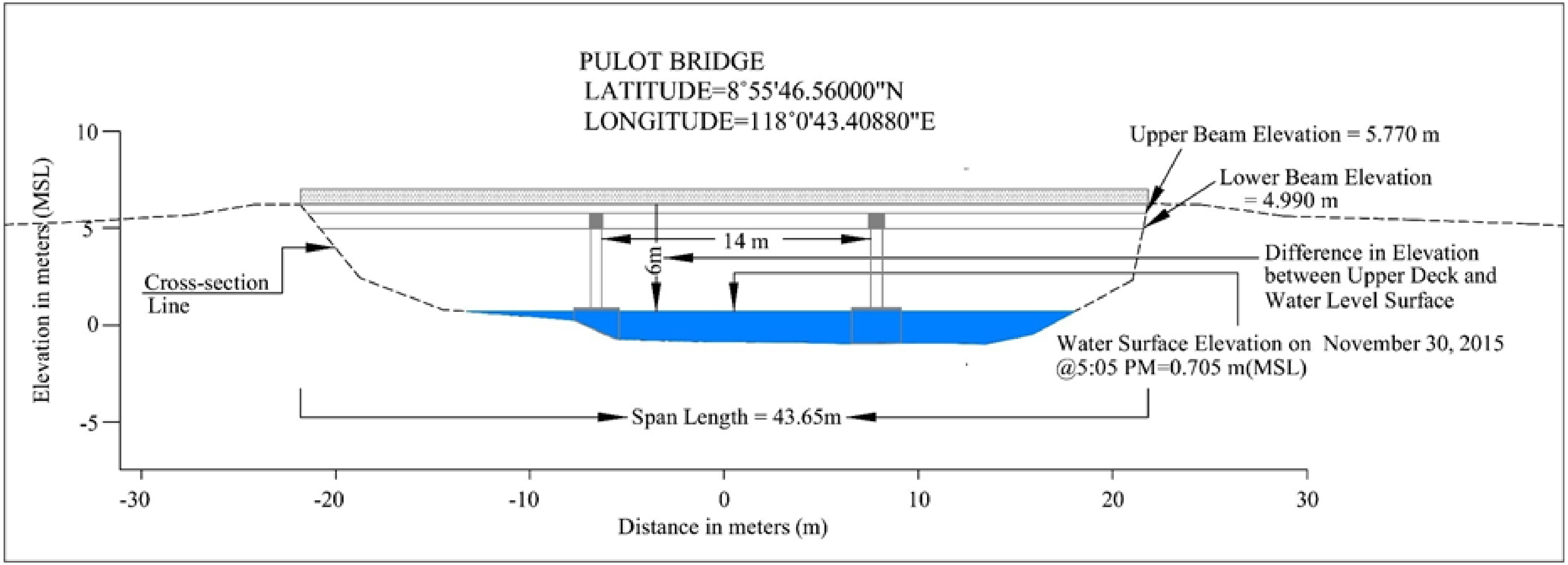


Figure 34. Pulot Bridge Cross-section Diagram

Bridge Data Form

Bridge Name: PULOT BRIDGE

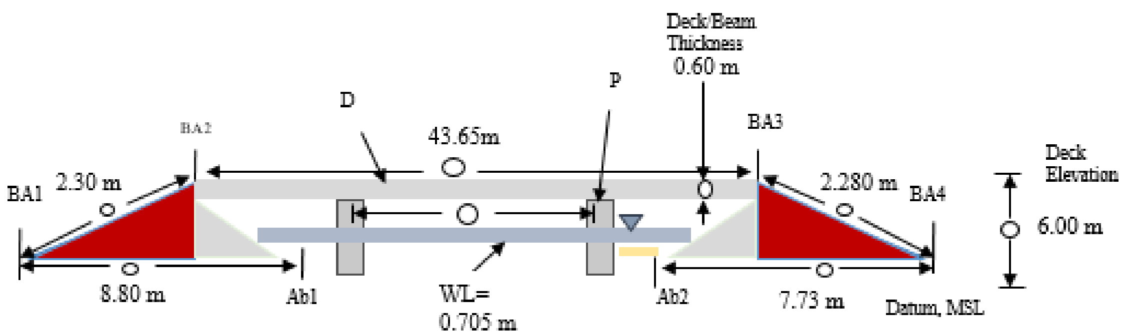
River Name: PULOT RIVER
Location (Brgy,City,Region): Brgy. Pulot Shore, Sofronio Española, Palawan

Survey Team: William Mamaril, Nilo Alpas
Date and Time: November 30, 2015, 5:05 PM

Flow Condition: low normal ✔ high

Weather Condition: ✔ fair rainy

Cross-sectional View (not to scale)



Legend:
BA = Bridge Approach
P = Pier
Ab = Abutment
D = Deck
WL = Water Level/Surface
MSL = Mean Sea Level
◯ = Measurement Value

Line Segment	**Measurement (m)**	**Remarks**
1. BA1-BA2	2.30 m	
2. BA2-BA3	43.65 m	
3. BA3-BA4	2.280 m	
4. BA1-Ab1	8.80m	
5. Ab2-BA4	7.73 m	
6. Deck/beam thickness	0.60 m	
7. Deck elevation	6.00 m	

Note: Observer should be facing downstream

Figure 35. Pulot Bridge Data Sheet

The water surface elevation of Pulot River was determined by a Horizon® Total Station on November 30, 2015 at 5:05 PM at Pulot Bridge area with a value of 0.705 m in MSL as shown in Figure 34. This was translated into marking on the bridge's pier as shown in Figure 36. The marking served as reference for flow data gathering and depth gauge deployment of the partner HEI responsible for Pulot River, the University of the Philippines Los Baños.

Figure 36. Water-level markings on Pulot Bridge

4.6 Validation Points Acquisition Survey

Validation points acquisition survey was conducted by DVBC from August 16-28, 2016 using a survey grade GNSS Rover receiver, Trimble® SPS 985, mounted on a range pole which was attached on the side of the vehicle as shown in Figure 37. It was secured with cable ties and ropes to ensure that it was horizontally and vertically balanced. The antenna height was 1.361 m and measured from the ground up to the bottom of the quick release of the GNSS Rover receiver. The PPK technique utilized for the conduct of the survey was set to continuous topo mode with PLW-122 occupied as the GNSS base station in the conduct of the survey.

Figure 37. Validation points acquisition survey set-up for Pulot River

The survey started from Brgy. Mambalot, Municipality of Brookes Point, Palawan going north west along national high way covering three (3) barangays in the Municipality of Brookes Point, seven (7) barangays in Sofronio Española, and six (6) barangays in Narra, and ended in Brgy. Princess Urduja, Municipality of Narra, Palawan. Concrete roads were very sparse along the Pulot River Basin as shown in Figure 39; hence, few validation points were acquired. The survey gathered a total of 3,885 points with approximate length of 75.58 km using PLW-122 as GNSS base station for the entire extent of validation points acquisition survey as illustrated in the map in Figure 38.

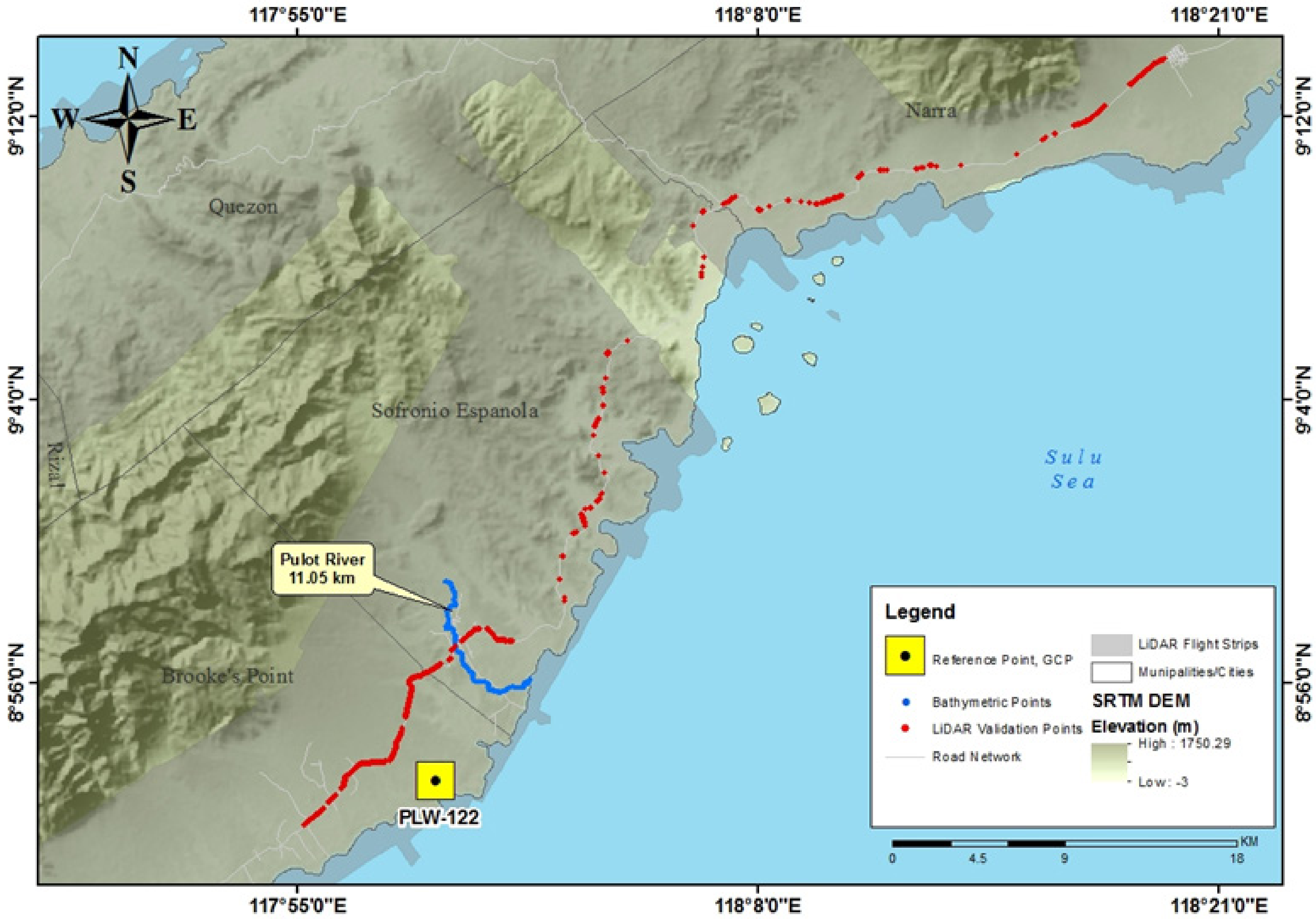


Figure 38. Validation points acquisition covering the Pulot River Basin Area

Figure 39. Terrain along Pulot River Basin

4.7 River Bathymetric Survey

Bathymetric survey was executed fromJanuary 28, 2016 using aHi-Target™Echo Sounder and a Horizon™Total Station as illustrated in Figures 40 and 41. The survey started from the in Brgy. Iraray in Municipality of Sofronio Española, Palawan with coordinates 8°59'13.72136"N, 117°58'48.46797"E and ended at mouth of the river of the river in Brgy. Pulot Shore, Municipality of Sofronio Española as well, with coordinates 8°55'58.26109"N, 118°1'27.9945"E. The control pointsUP_PUL-1 and UP_PUL-2were used as GNSS base stations all throughout the entire survey.

No bathymetric checking points were gathered for Pulot River due to heavy rains caused by the southwest monsoon on August 23, 2016, which rendered the river unnavigable, both on foot and by boat by the time of quality checking.

A CAD drawing was also produced to illustrate the riverbed profile of Pulot River. As shown in Figure 43, the highest and lowest elevation has a 22-m difference. The highest elevation observed was 18.0 m above MSL located in Brgy. Iraray, Municipality of Sofronio Española while the lowest was -4.427 m below MSL located in Brgy. Pulot Shore, Municipality of Sofronio Española.

Figure 40. Bathymetric survey of ABSD at PulotRiver using Hi-Target™ EchoSounder (downstream)

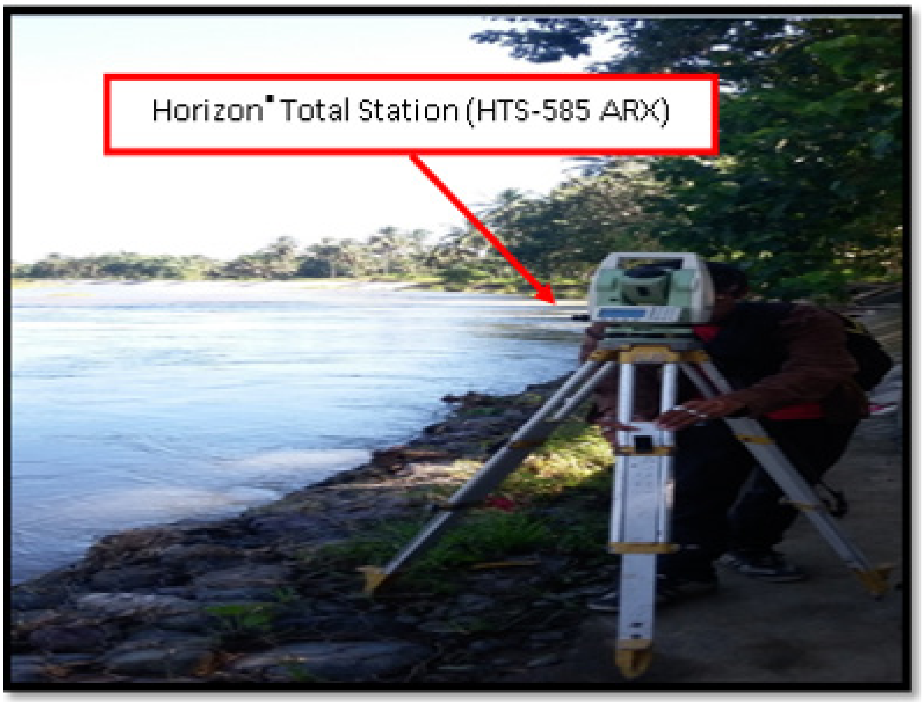


Figure 41. Bathymetric survey of ABSD at Pulot River using Horizon™ Total Station

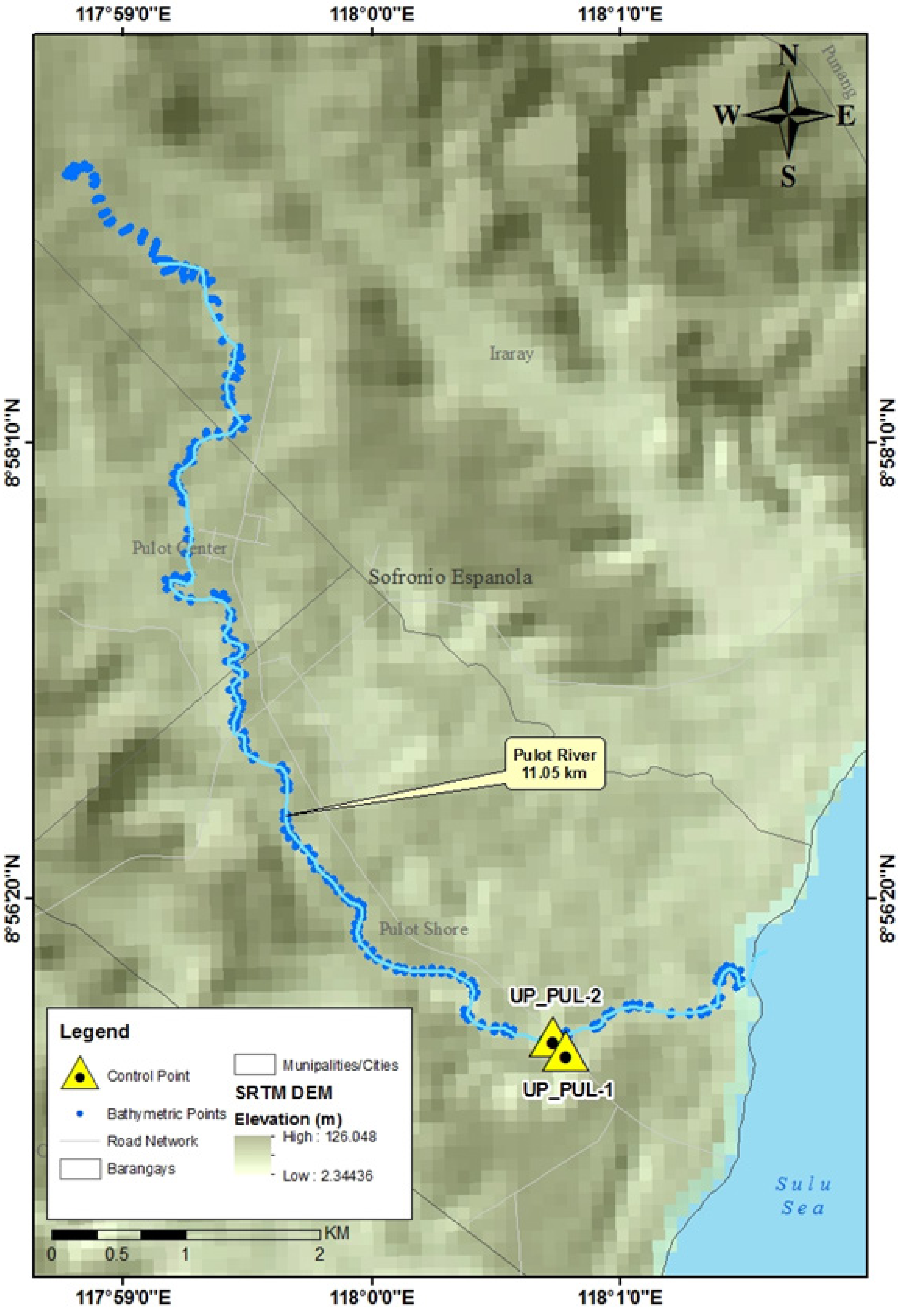


Figure 42. Manual bathymetric survey of Pulot River

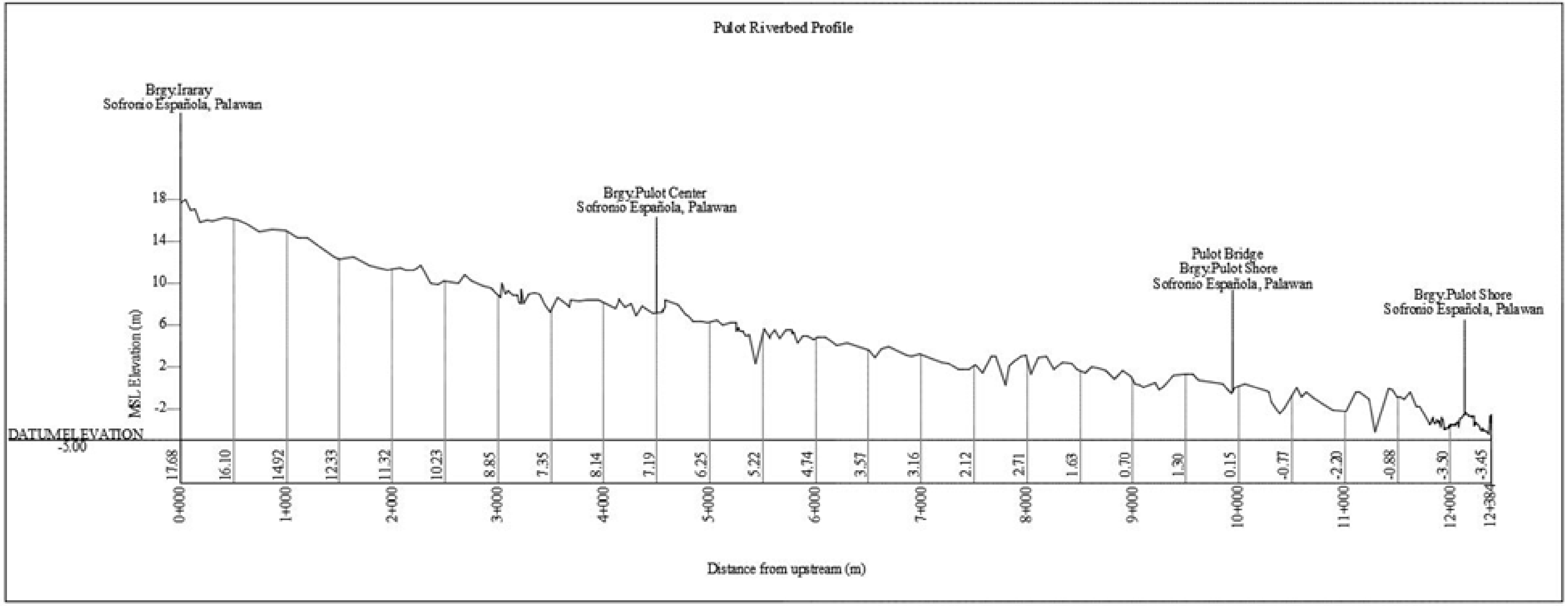


Figure 43. Pulot Riverbed Profile

CHAPTER 5: FLOOD MODELING AND MAPPING

Dr. Alfredo Mahar Lagmay, Christopher Uichanco, Sylvia Sueno, Marc Moises, Hale Ines, Miguel del Rosario, Kenneth Punay, Neil Tingin, and Khristoffer Quinton, John Alvin B. Reyes, Alfi Lorenz B. Cura, Angelica T. Magpantay, Maria Michaela A. Gonzales Paulo Joshua U. Quilao, Jayson L. Arizapa, Kevin M. Manalo

The methods applied in this chapter were based on the DREAM methods manual (Lagmay et al., 2014) and further enhanced and updated in Paringit et al. (2017).

5.1 Data Used for Hydrologic Modeling

5.1.1 Hydrometry and Rating Curves

Components and data that affect the hydrologic cycle of the Pulot River Basin were monitored, collected, and analyzed. Rainfall, water level, and flow in a certain period of time, which may affect the hydrologic cycle of the Pulot River Basin were monitored, collected, and analyzed.

5.1.2 Precipitation

Precipitation data was taken from a portable rain gauges installed within the watershed (8.971252° N, 117.999280° E) The location of the rain gauge is seen in Figure 44.

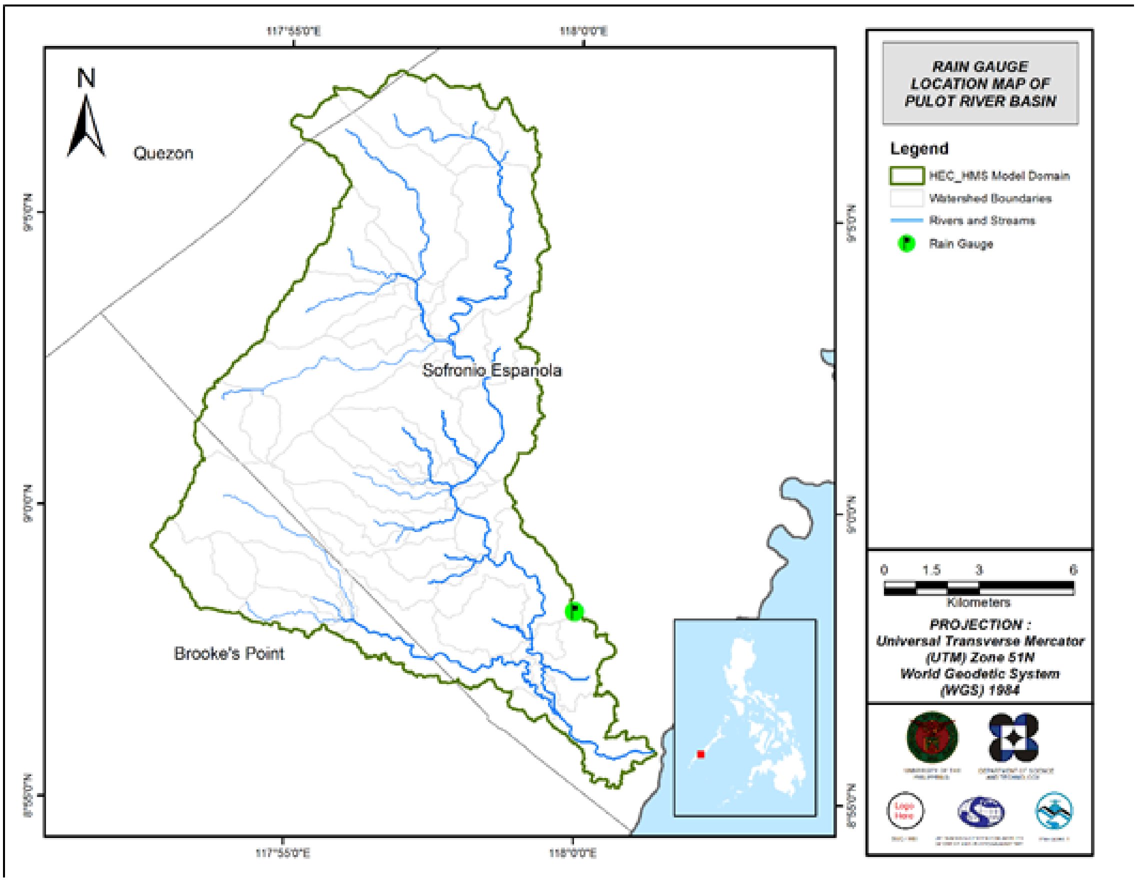


Figure 44. The location map of Pulot HEC-HMS model used for calibration

5.1.3 Rating Curves and River Outflow

A rating curve was developed at Pulot Bridge, Brooke's Point, Palawan (8.950120°N, 117.991071° E). It gives the relationship between the observed water levels from the Pulot Bridge and outflow of the watershed at this location using Bankfull Method in Manning's Equation.

For Pulot Bridge, the rating curve is expressed as Q = 56.072x2 -1006.60x +4517.80as shown in Figure 46.

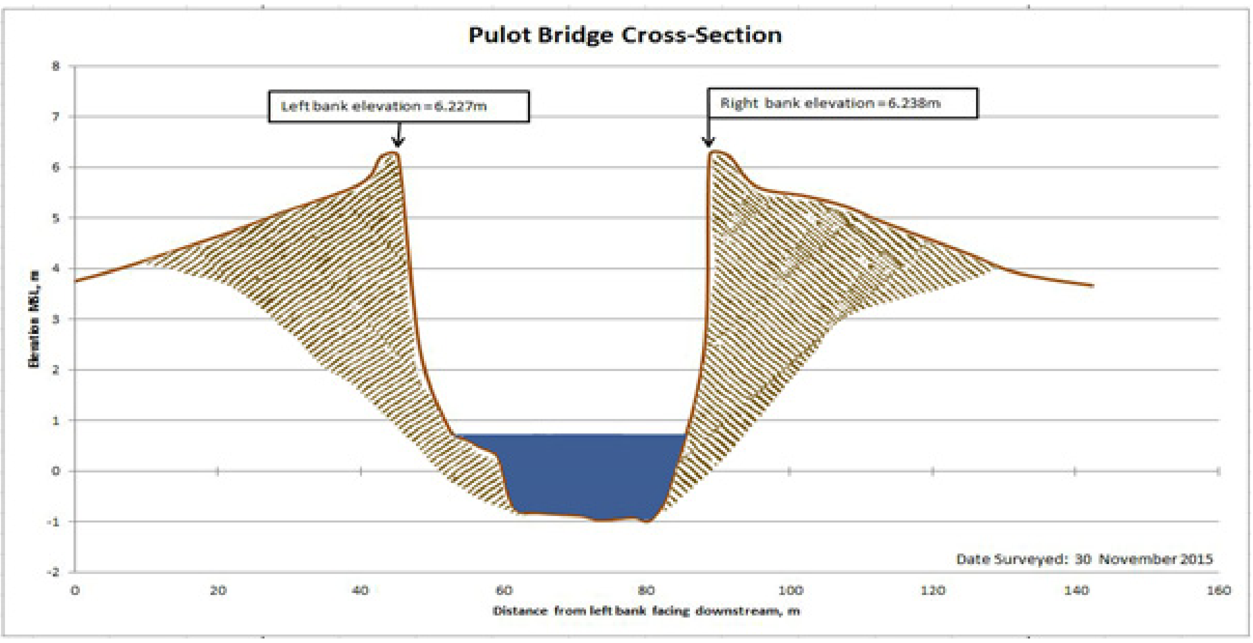


Figure 45. Cross-Section Plot of Pulot Bridge

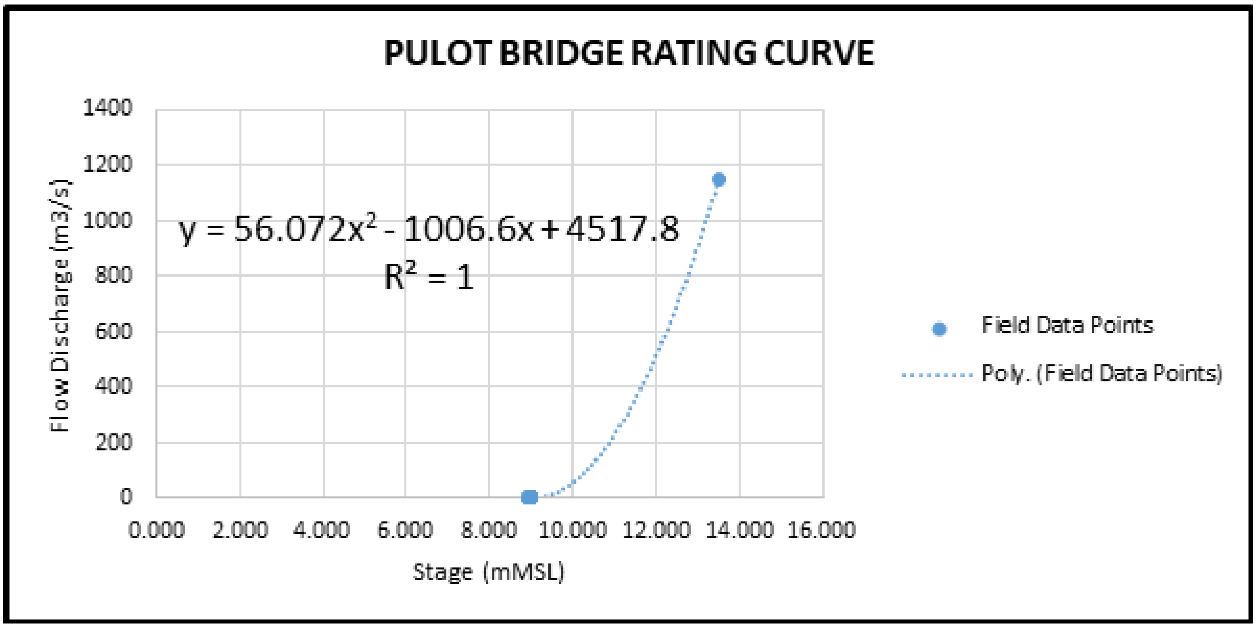


Figure 46. Rating Curve at Pulot Bridge, Brooke’s Point, Palawan

For the calibration of the HEC-HMS model, shown in Figure 47, actual flow discharge during a rainfall event was collected in the Pulot bridge. Peak discharge is 20.70cu.m/s on February 24, 2017 at 12:15 pm.

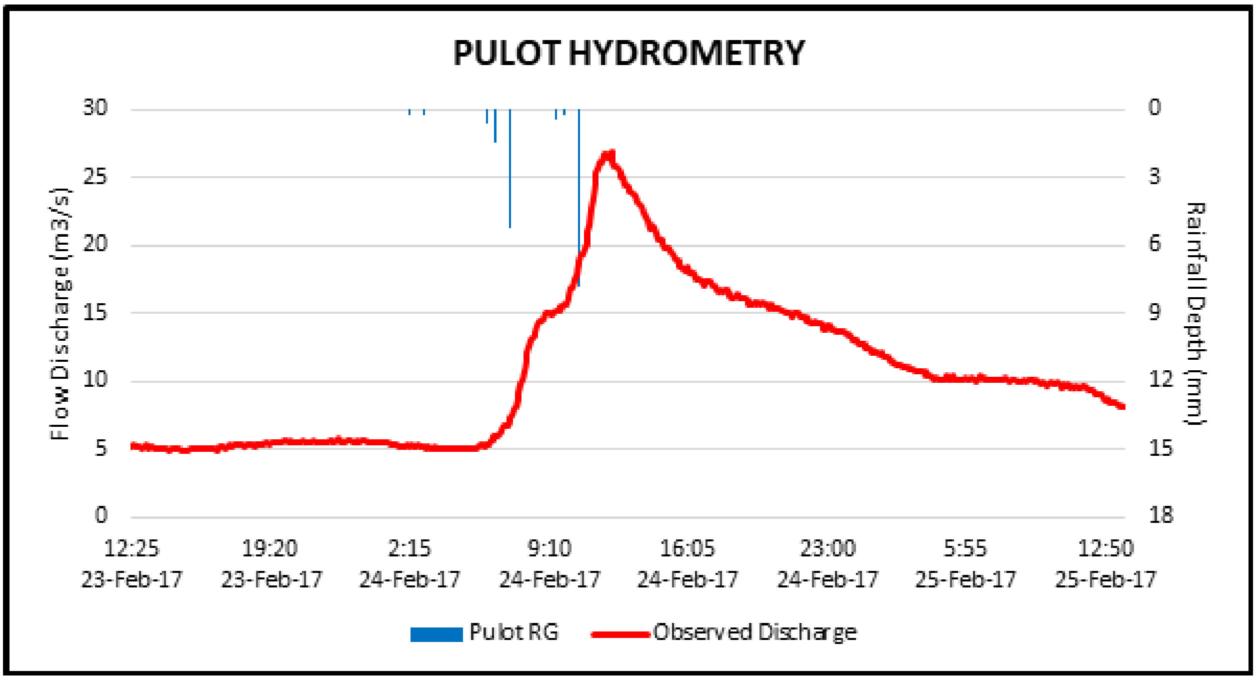


Figure 47. Rainfall and outflow data at Pulot used for modeling

5.2 RIDF Station

The Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA) computed Rainfall Intensity Duration Frequency (RIDF) values for the Puerto Princesa Rain Gauge. The RIDF rainfall amount for 24 hours was converted to a synthetic storm by interpolating and re-arranging the values in such a way a certain peak value will be attained at a certain time. This station was chosen based on its proximity to the Pulot watershed. The extreme values for this watershed were computed based on a 58-year record.

Table 22. RIDF values for Puerto Princesa Rain Gauge computed by PAGASA

COMPUTED EXTREME VALUES (in mm) OF PRECIPITATION									
T (yrs)	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	14.8	22	27.3	36.2	49.8	58.8	75.1	88	104.1
5	21.3	31.9	39.7	52.3	73	86.9	112.8	135.4	156.4
10	25.6	38.5	48	63	88.4	105.5	137.8	166.8	191.1
15	28.1	42.2	52.6	69	97	116	151.9	184.5	210.6
20	29.8	44.7	55.9	73.3	103.1	123.4	161.7	196.8	224.3
25	31.1	46.7	58.4	76.5	107.8	129.1	169.3	206.4	234.9
50	35.2	52.9	66.1	86.5	122.2	146.5	192.7	235.8	267.3
100	39.2	59	73.7	96.4	136.5	163.8	216	265	299.6

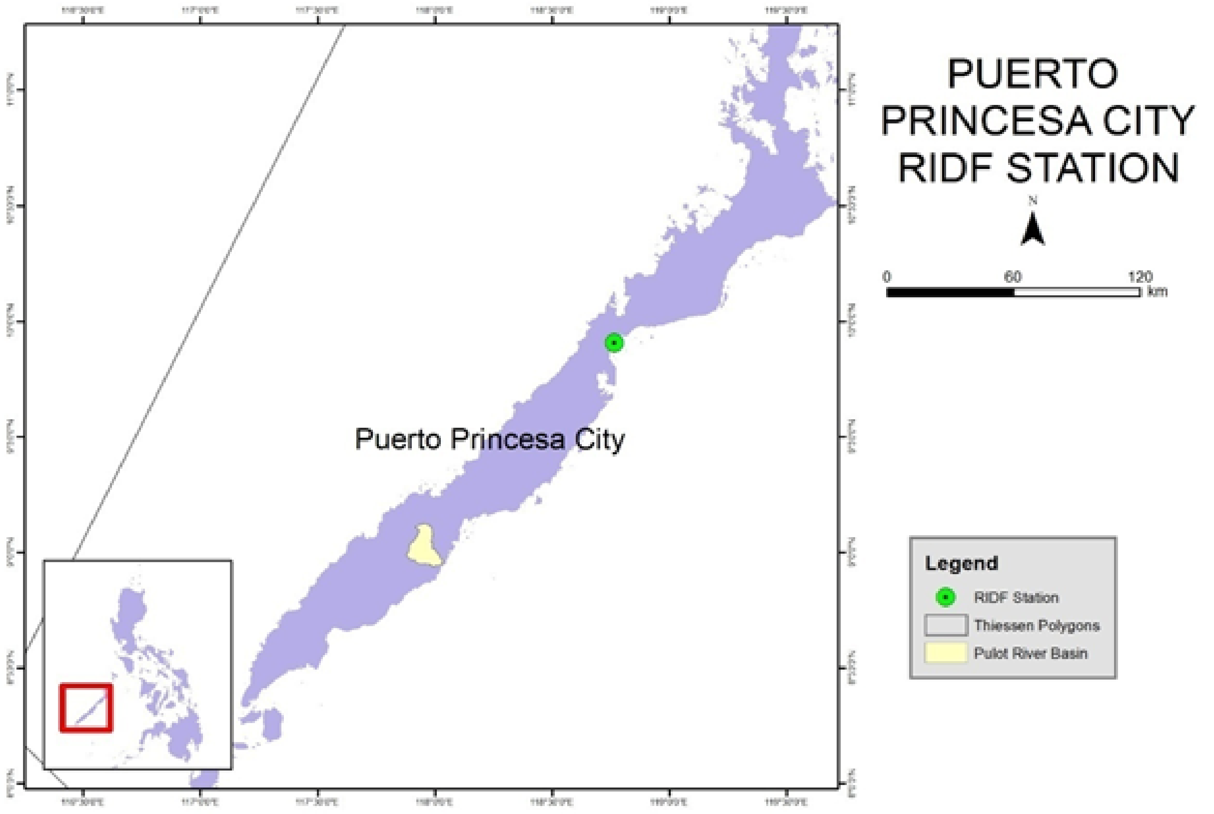


Figure 48. Location of Puerto Princesa RIDF relative to Pulot River Basin

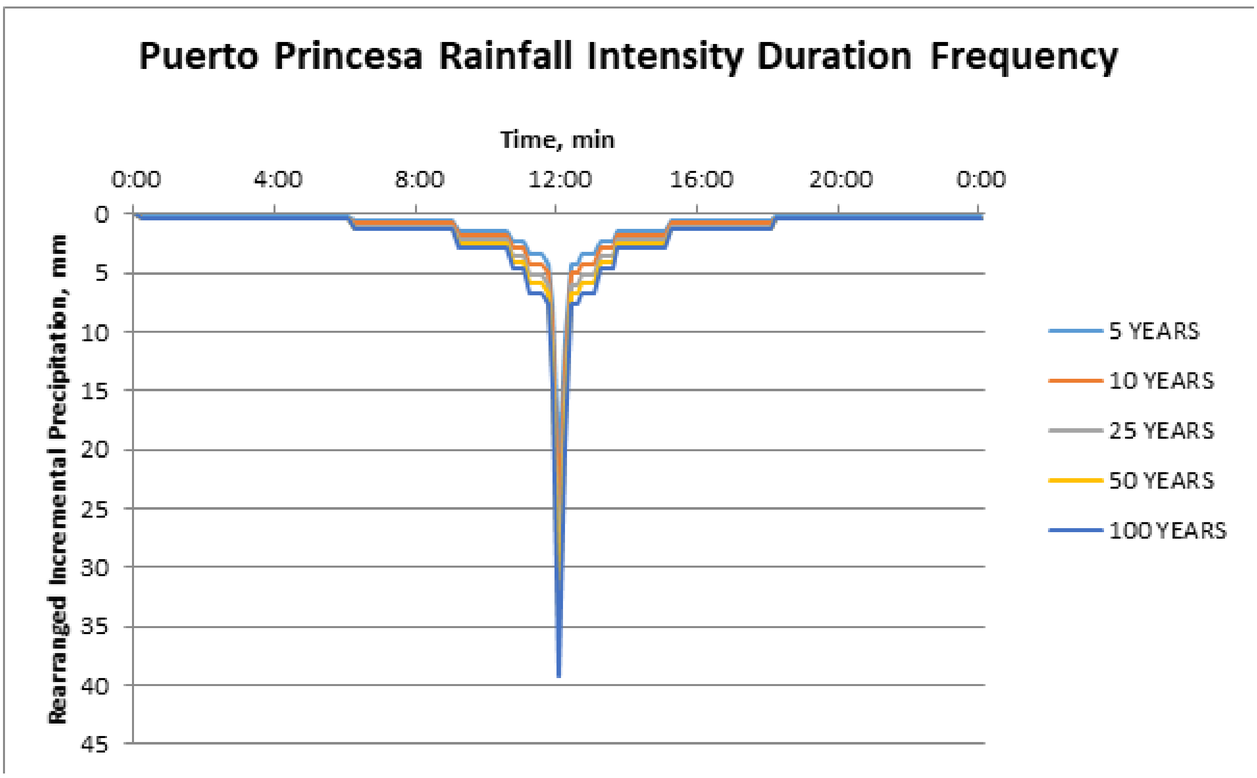


Figure 49. Synthetic Storm Generated For A 24-hr Period Rainfall For Various Return Periods

5.3 HMS Model

The soil dataset was taken from and generated by the Bureau of Soils and Water Management (BSWM) under the Department of Agriculture. The land cover dataset is from the National Mapping and Resource information Authority (NAMRIA).

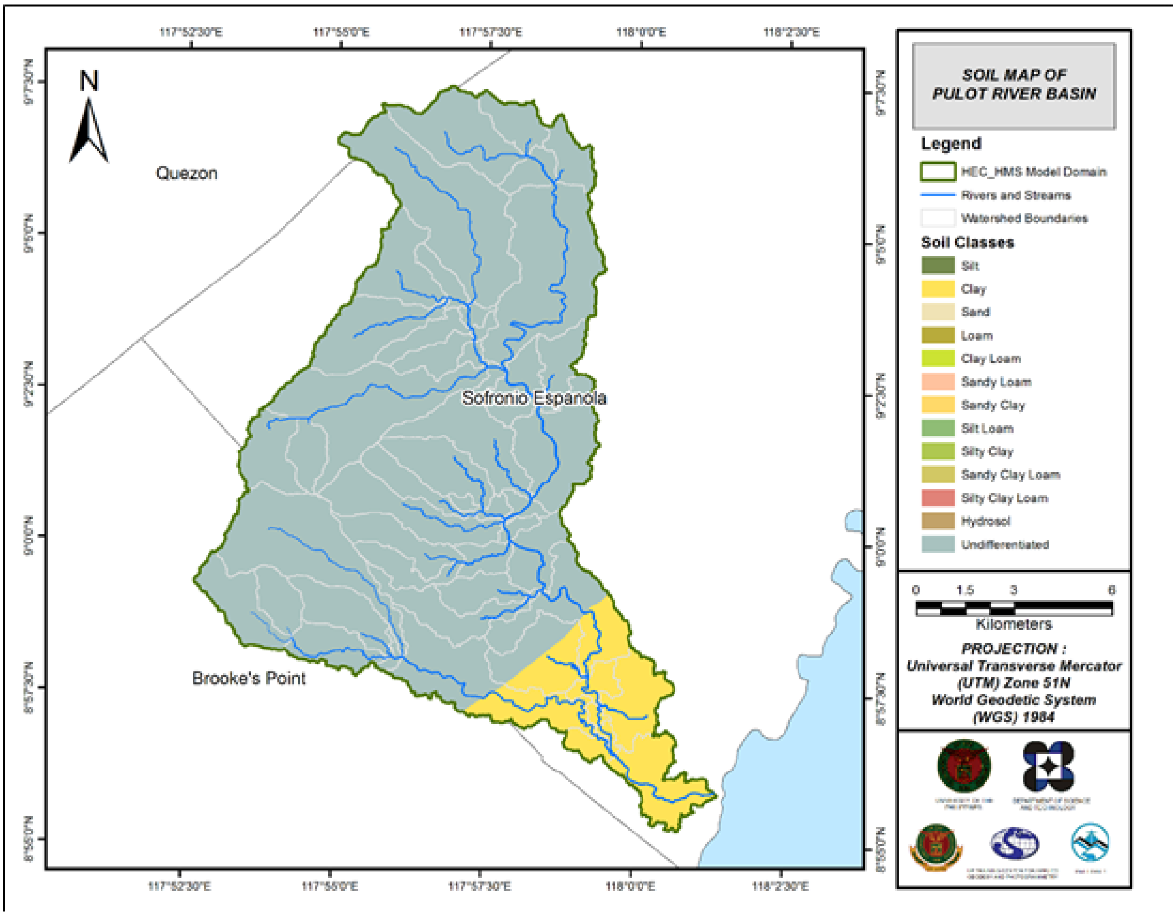


Figure 50. The soil map of the Pulot River Basin used for the estimation of the CN parameter. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

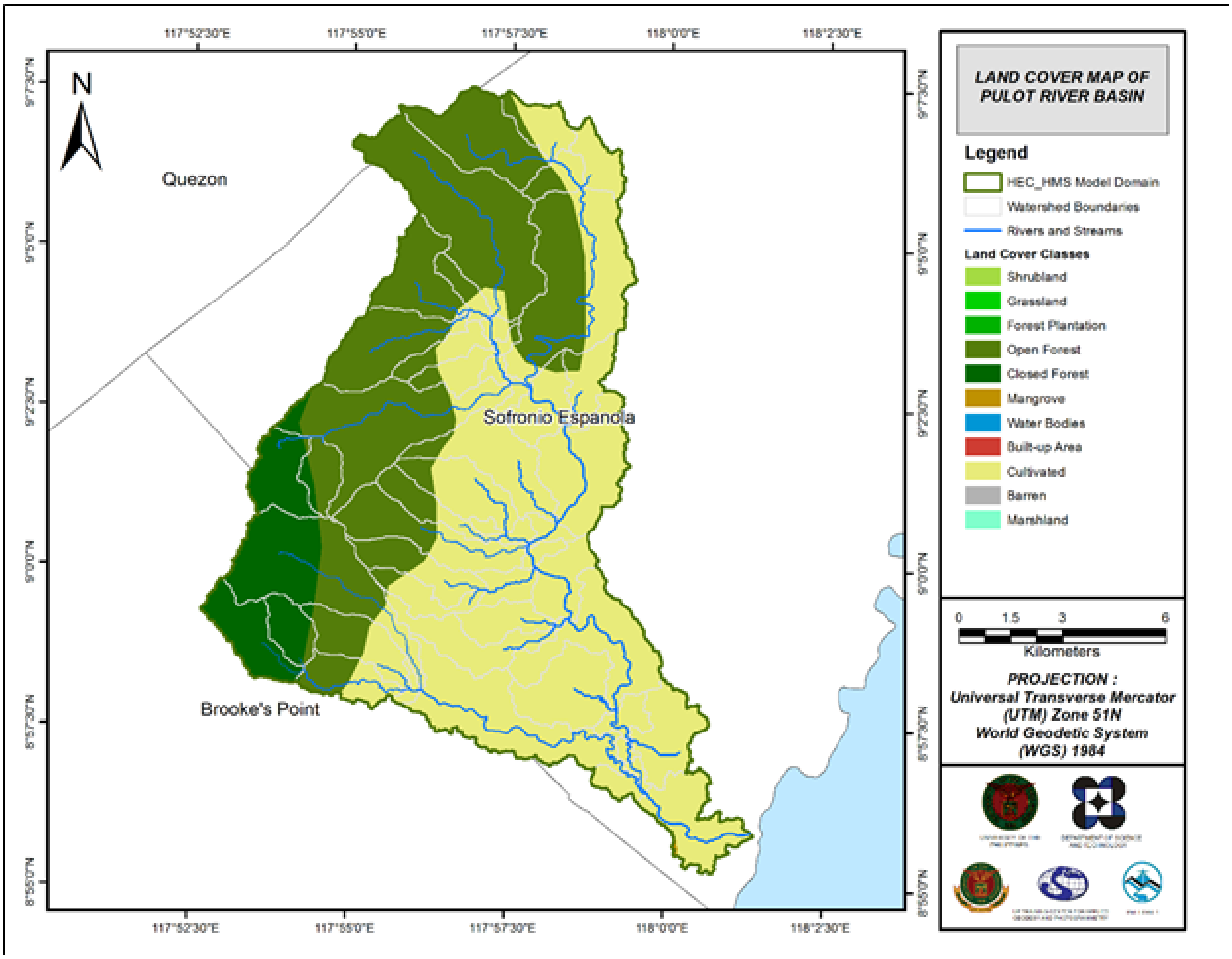


Figure 51. The land cover map of the Pulot River Basin used for the estimation of the CN and watershed lag parameters of the rainfall-runoff model. (Source of data: Digital soil map of the Philippines published by the Bureau of Soil and Water Management – Department of Agriculture)

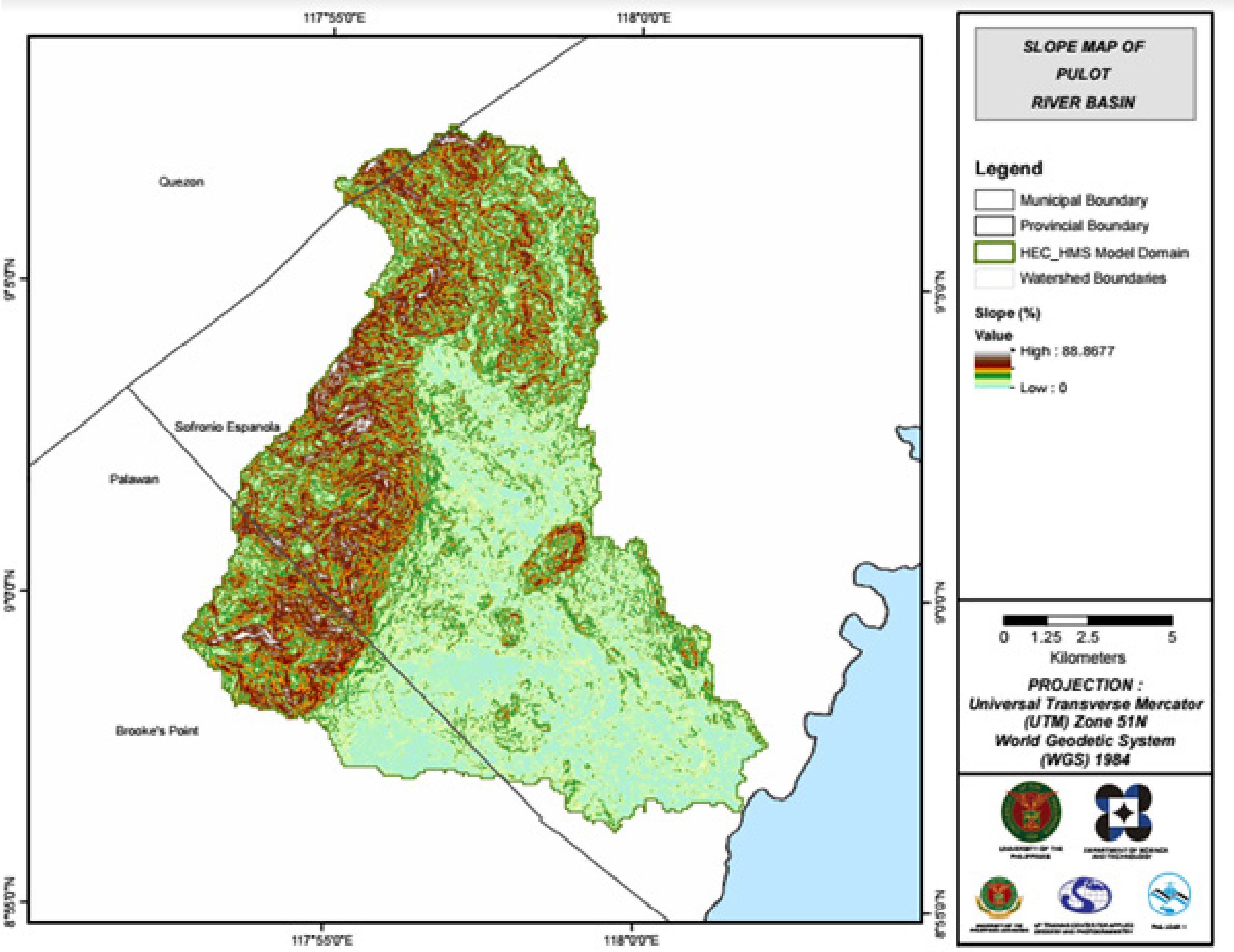


Figure 52. Slope Map of the Pulot River Basin

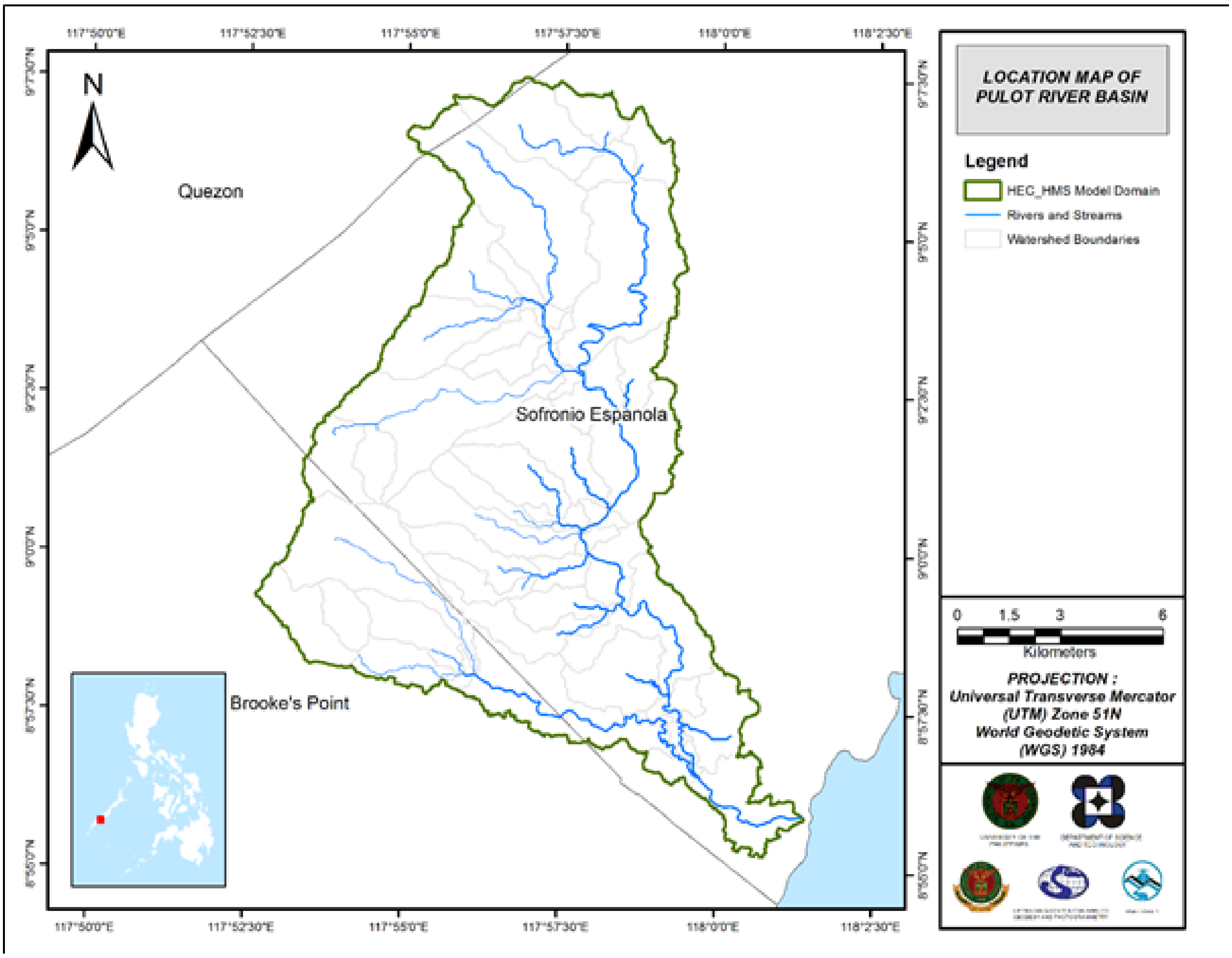


Figure 53. Stream Delineation Map of the Pulot River Basin

Using SAR-based DEM, the Pulot basin was delineated and further subdivided into subbasins. The model consists of 51 sub basins, 26 reaches, and 26 junctions. The main outlet is at Pulot Bridge.

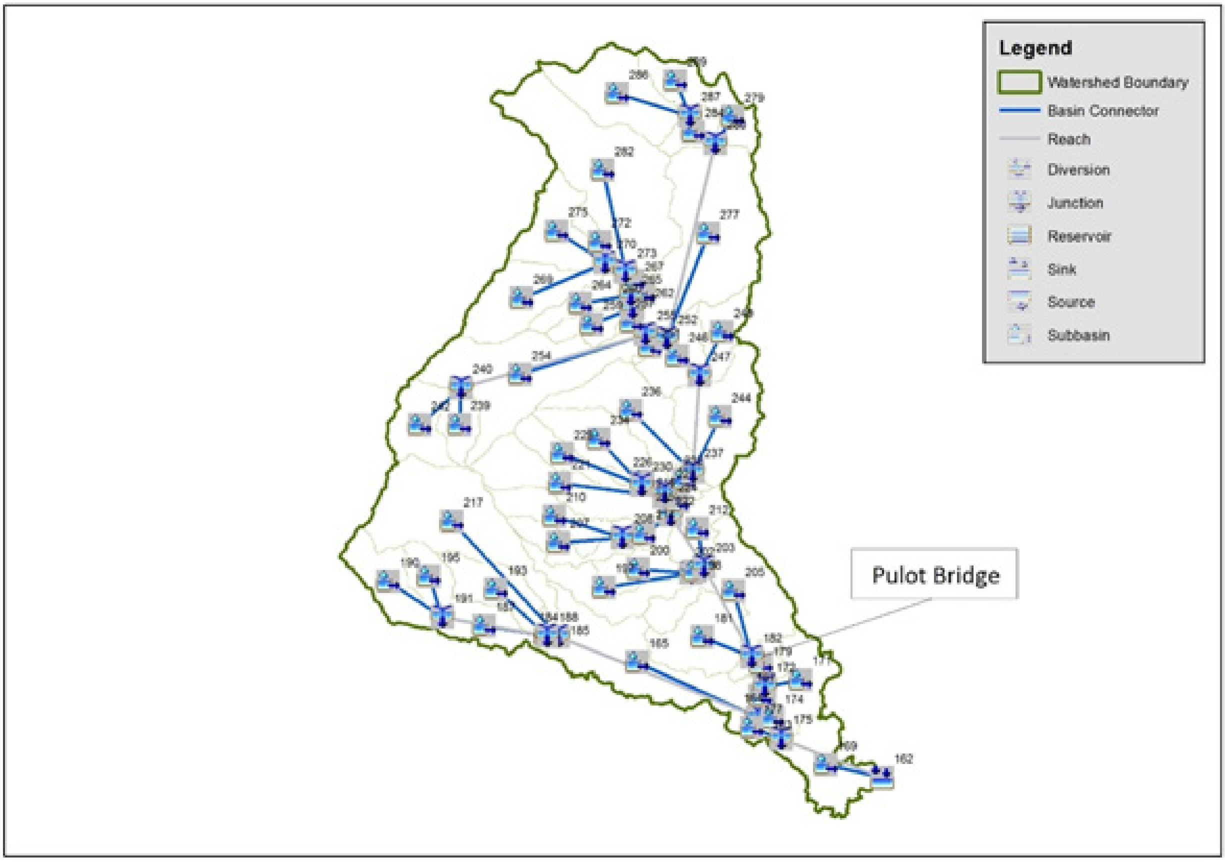


Figure 54. The Pulot river basin model generated using HEC-HMS

5.4 Cross-section Data

Riverbed cross-sections of the watershed are crucial in the HEC-RAS model setup. The cross-section data for the HEC-RAS model was derived using the LiDAR DEM data. It was defined using the Arc GeoRAS tool and was post-processed in ArcGIS.

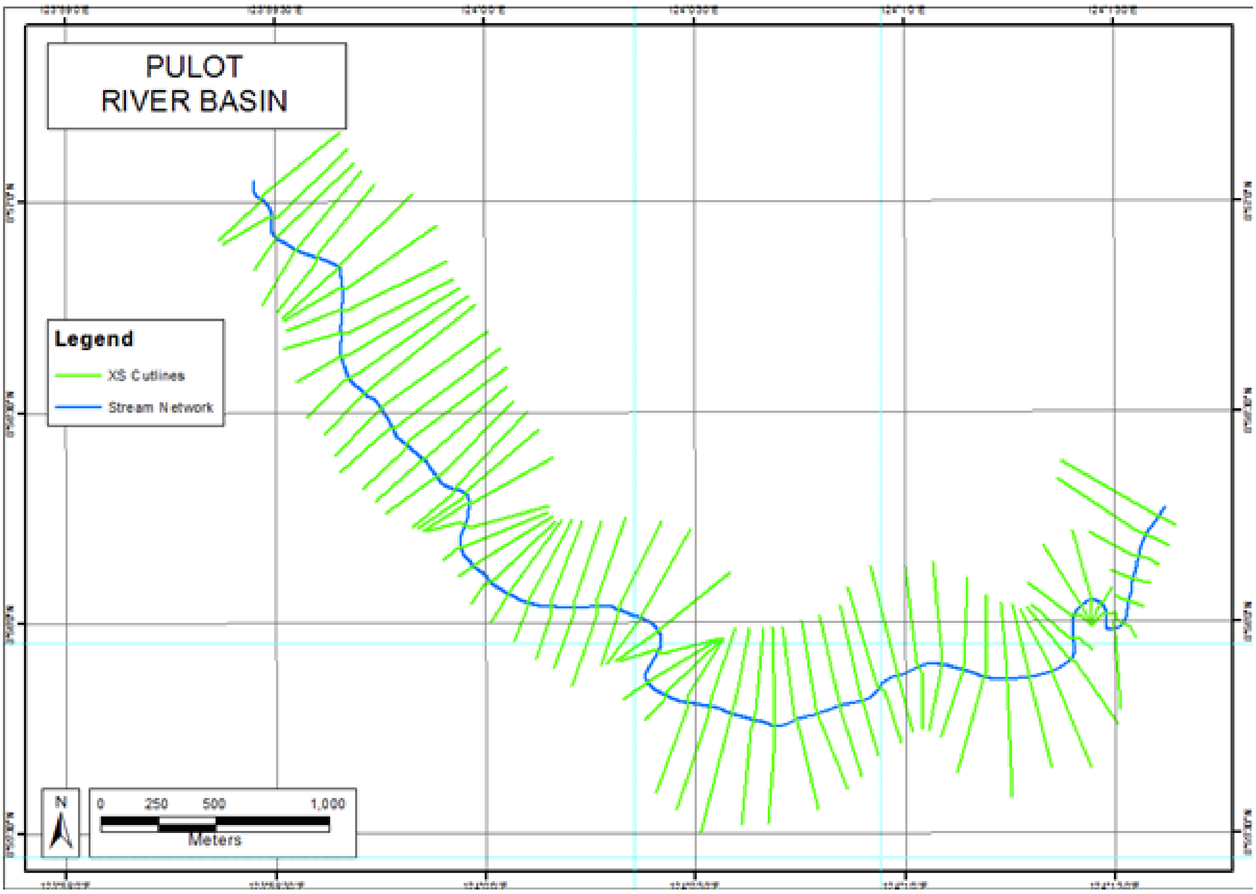


Figure 55. River cross-section of Pulot River generated through Arcmap HEC GeoRAS tool

5.5 Flo 2D Model

The automated modelling process allows for the creation of a model with boundaries that are almost exactly coincidental with that of the catchment area. As such, they have approximately the same land area and location. The entire area is divided into square grid elements, 10 meter by 10 meter in size. Each element is assigned a unique grid element number which serves as its identifier, then attributed with the parameters required for modelling such as x-and y-coordinate of centroid, names of adjacent grid elements, Manning coefficient of roughness, infiltration, and elevation value. The elements are arranged spatially to form the model, allowing the software to simulate the flow of water across the grid elements and in eight directions (north, south, east, west, northeast, northwest, southeast, southwest).

Based on the elevation and flow direction, it is seen that the water will generally flow from the nothwest of the model to the southeast, following the main channel. As such, boundary elements in those particular regions of the model are assigned as inflow and outflow elements respectively.

Figure 56. Screenshot of subcatchment with the computational area to be modeled in FLO-2D GDS Pro

The simulation is then run through FLO-2D GDS Pro. This particular model had a computer run time of 62.63345 hours. After the simulation, FLO-2D Mapper Pro is used to transform the simulation results into spatial data that shows flood hazard levels, as well as the extent and inundation of the flood. Assigning the appropriate flood depth and velocity values for Low, Medium, and High creates the following food hazard map. Most of the default values given by FLO-2D Mapper Pro are used, except for those in the Low hazard level. For this particular level, the minimum h (Maximum depth) is set at 0.2 m while the minimum vh (Product of maximum velocity (v) times maximum depth (h)) is set at 0 m2/s.

The creation of a flood hazard map from the model also automatically creates a flow depth map depicting the maximum amount of inundation for every grid element. The legend used by default in Flo-2D Mapper is not a good representation of the range of flood inundation values, so a different legend is used for the layout. In this particular model, the inundated parts cover a maximum land area of 64 510 000.00 m2.

There is a total of 42 747 789.73 m3 of water entering the model. Of this amount, 18 588 531.68 m3 is due to rainfall while 24 159 258.05 m3 is inflow from other areas outside the model. 8 175 795.00m3 of this water is lost to infiltration and interception, while 9 329 574.60 m3 is stored by the flood plain. The rest, amounting up to 25 242 431.55 m3, is outflow.

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5.6 Results of HMS Calibration

After calibrating the Pulot HEC-HMS river basin model, its accuracy was measured against the observed values. Figure 57 shows the comparison between the two discharge data.

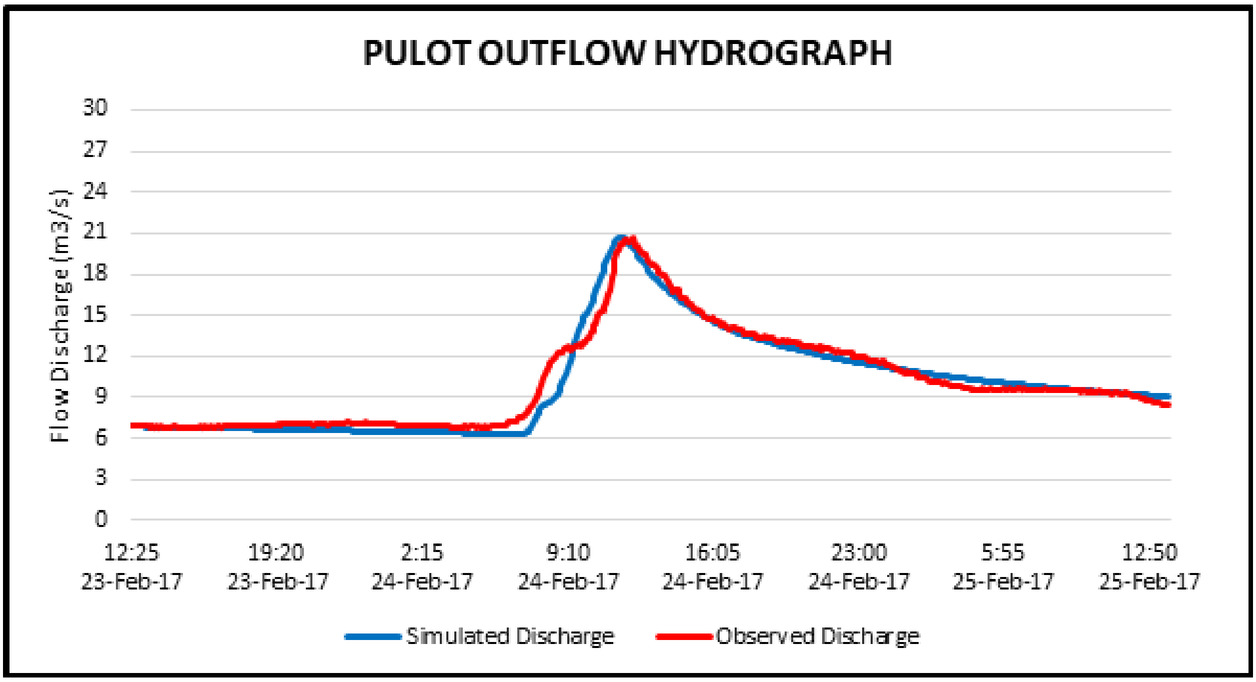

Figure 57. Outflow Hydrograph of Pulot produced by the HEC-HMS model compared with observed outflow

Enumerated in Table 23 are the adjusted ranges of values of the parameters used in calibrating the model.

Table 23. Range of Calibrated Values for Pulot River Basin

Hydrologic Element	Calculation Type	Method	Parameter	Range of Calibrated Values
Basin	Loss	SCS Curve number	Initial Abstraction (mm)	0.01 - 12
			Curve Number	55 - 99
	Transform	Clark Unit Hydrograph	Time of Concentration (hr)	0.06 - 12
			Storage Coefficient (hr)	0.02 - 8
	Baseflow	Recession	Recession Constant	0.1 - 1
			Ratio to Peak	0.09 - 1
Reach	Routing	Muskingum-Cunge	Manning's Coefficient	0.04

Initial abstraction defines the amount of precipitation that must fall before surface runoff. The magnitude of the outflow hydrograph increases as initial abstraction decreases. The range of values from 0.01 to 12mm means that there is minimal amount of infiltration or rainfall interception by vegetation.

Curve number is the estimate of the precipitation excess of soil cover, land use, and antecedent moisture. The magnitude of the outflow hydrograph increases as curve number increases. The range of 55 to 89 for curve number is advisable for Philippine watersheds depending on the soil and land cover of the area (M. Horritt, personal communication, 2012).

Time of concentration and storage coefficient are the travel time and index of temporary storage of runoff in a watershed. The range of calibrated values from 0.06 hours to 12 hours determines the reaction time of the model with respect to the rainfall. The peak magnitude of the hydrograph also decreases when these parameters are increased.

Recession constant is the rate at which baseflow recedes between storm events and ratio to peak is the ratio of the baseflow discharge to the peak discharge. For this parameter, the characteristics of this watershed differs per subbasin.

Manning's roughness coefficient of 0.01 to 0.04 also indicates different characteristics of the river reaches.

Table 24. Summary of the Efficiency Test of Pulot HMS Model

Accuracy Measure	Value
Root Mean Square Error (RMSE)	0.744
Pearson Correlation Coefficient (r2)	0.916
Nash-Sutcliffe (E)	0.955
Percent Bias (PBIAS)	1.633
Observation Standard Deviation Ratio (RSR)	0.213

The Root Mean Square Error (RMSE) method aggregates the individual differences of these two measurements. It was identified at 0.744.

The Pearson correlation coefficient (r2) assesses the strength of the linear relationship between the observations and the model. This value being close to 1 corresponds to an almost perfect match of the observed discharge and the resulting discharge from the HEC HMS model. Here, it measured 0.916.

The Nash-Sutcliffe (E) method was also used to assess the predictive power of the model. Here the optimal value is 1. The model attained an efficiency coefficient of 0.955.

A positive Percent Bias (PBIAS) indicates a model's propensity towards under-prediction. Negative values indicate bias towards over-prediction. Again, the optimal value is 0. In the model, the PBIAS is 1.633.

The Observation Standard Deviation Ratio, RSR, is an error index. A perfect model attains a value of 0 when the error in the units of the valuable a quantified. The model has an RSR value of 0.213.

5.7 Calculated Outflow hydrographs and Discharge Values for different Rainfall Return Periods

5.7.1 Hydrograph using the Rainfall Runoff Model

The summary graph (Figure 58) shows the Pulot outflow using the Puerto Princesa RIDF in 5 different return periods (5-year, 10-year, 25-year, 50-year, and 100-year rainfall time series) based on the PAGASA data. The simulation results reveal significant increase in outflow magnitude as the rainfall intensity increases for a range of durations and return periods.

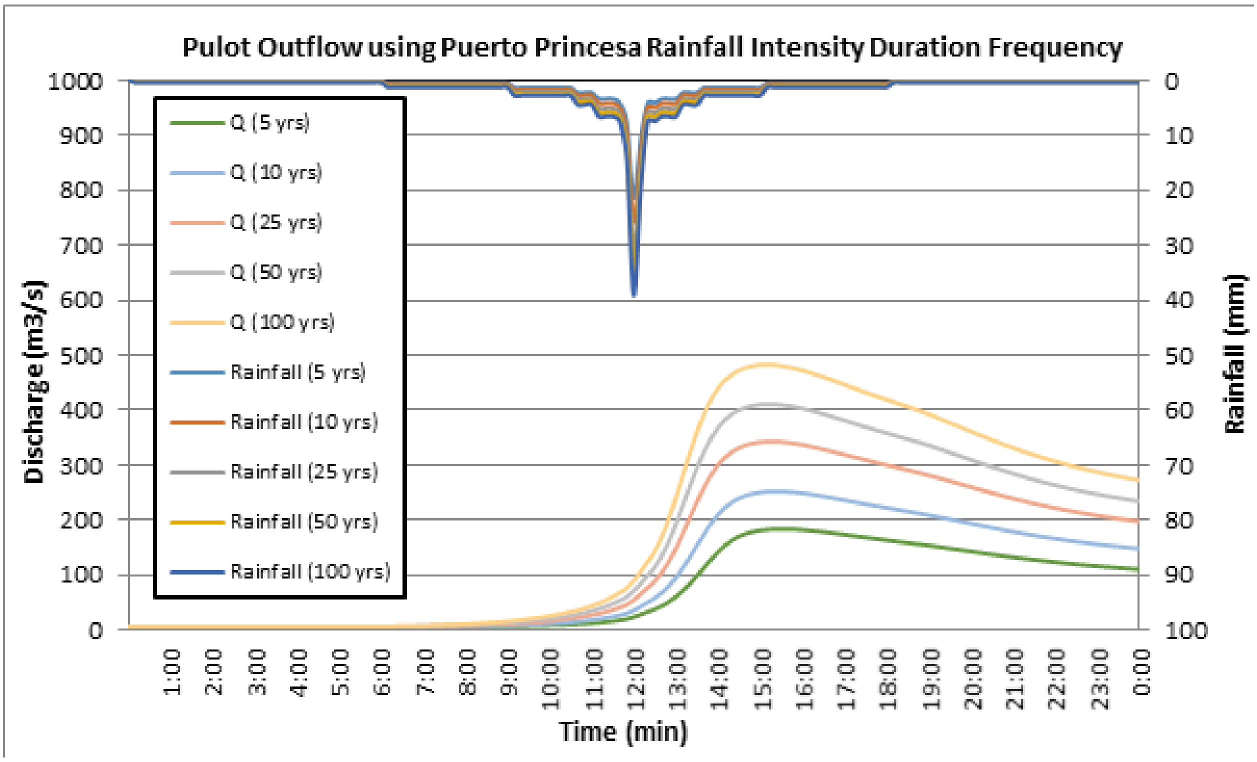

Figure 58. Outflow hydrograph at Pulot Station generated using Puerto Princesa RIDF simulated in HEC-HMS

A summary of the total precipitation, peak rainfall, peak outflow, time to peak and lag time of the Pulot discharge using the Puerto Princesa RIDF curves in five different return periods is shown in Table 25.

Table 25. Peak values of the Pulot HEC-HMS Model outflow using the Puerto Princesa RIDF

RIDF PERIOD	Total Precipitation (mm)	Peak Rainfall (mm)	Peak Outflow (cu.m/s)	Time to Peak
5-yr	156.40	21.30	185.874	3 hours 30 minutes
10-yr	191.10	25.60	253.093	3 hours 20 minutes
25-yr	234.90	31.10	343.194	3 hours 10 minutes
50-yr	267.30	25.20	412.867	3 hours 10 minutes
100-yr	299.60	39.20	483.138	3 hours 10 minutes

5.8 River Analysis (RAS) Model Simulation

The HEC-RAS Flood Model produced a simulated water level at every cross-section for every time step for every flood simulation created. The resulting model was used in determining the flooded areas within the model. The simulated model will be an integral part in determining real-time flood inundation extent of the river after it has been automated and uploaded on the DREAM website. The sample map of Pulot River using the HMS base flow is shown on Figure 59 below.

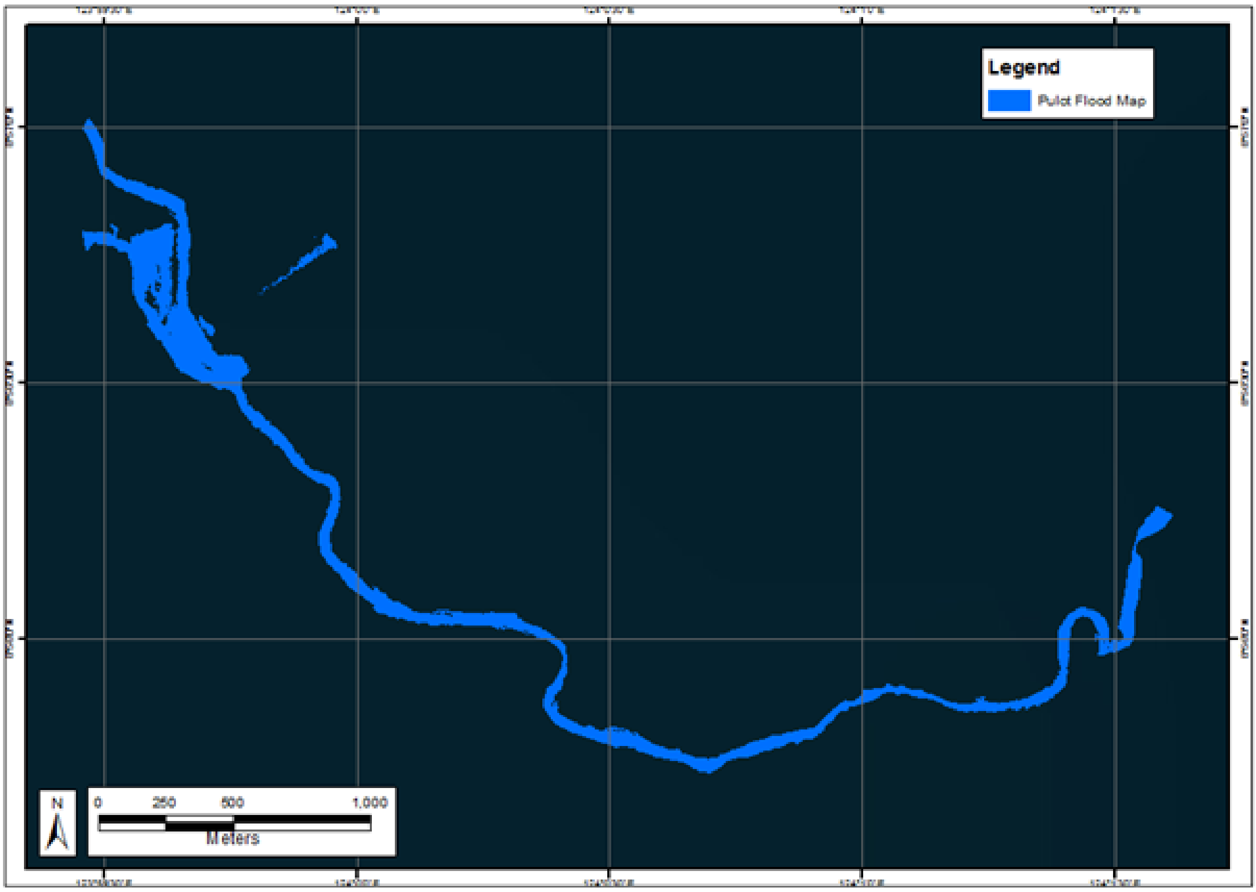

Figure 59. Pulot HEC-RAS Output

5.9 Flood Hazard and Flow Depth

The resulting hazard and flow depth maps for 100-, 25-, and 5-year rain return scenarios of the Pulot Floodplain are shown in Figure 60 to Figure 65. The floodplain, with an area of 123.81 sq. km., covers two municipalities namely Brooke's Point, and Sofronio Espanola. Table 26 shows the percentage of area affected by flooding per municipality.

Table 26. Municipalities affected in Pulot Floodplain

City / Municipality	Total Area	Area Flooded	% Flooded
Brooke's Point	893.39	4.39	0.49
Sofronio Espanola	477.50	119.32	24.99

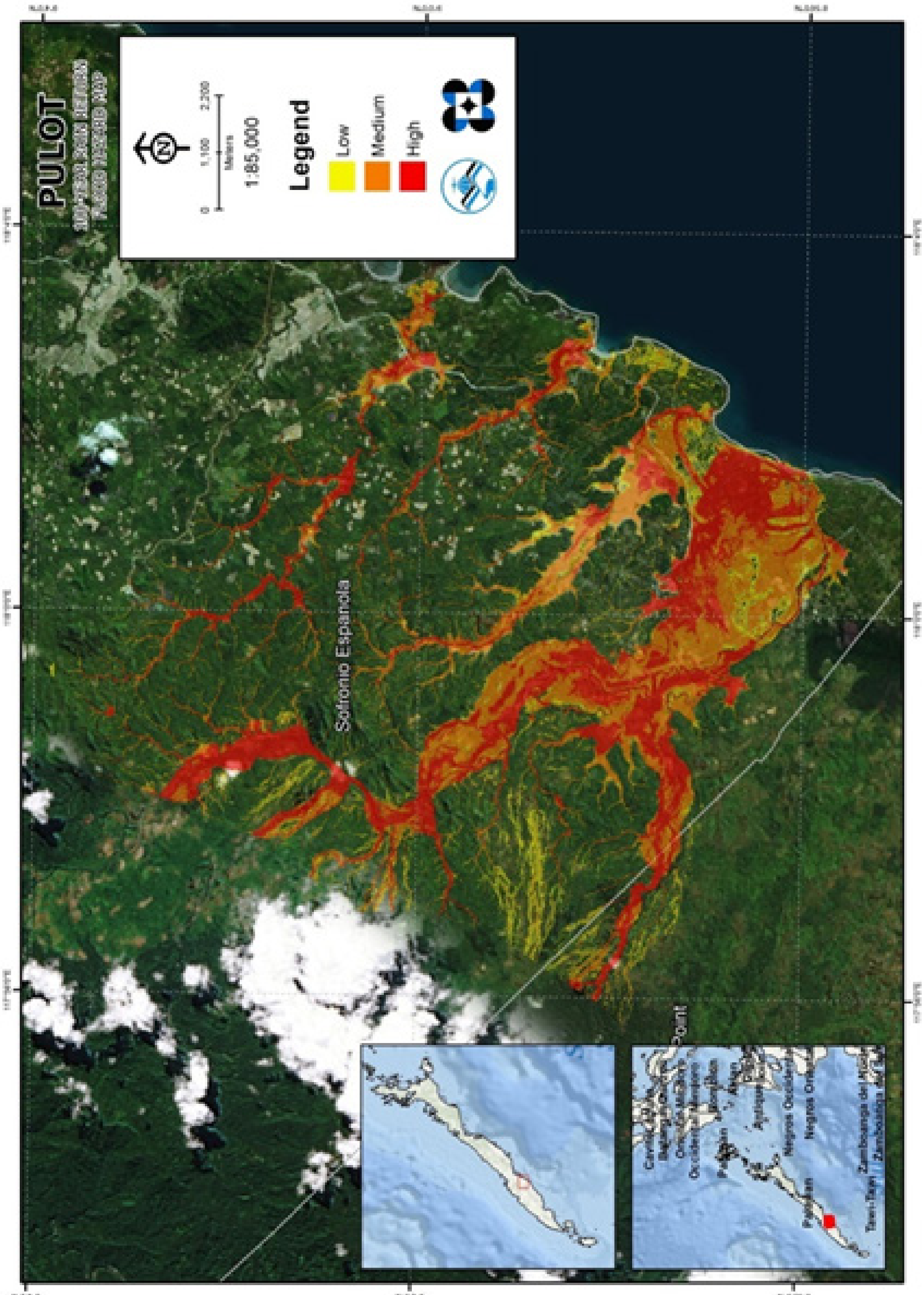

Figure 60. 100-year Flood Hazard Map for Pulot Floodplain

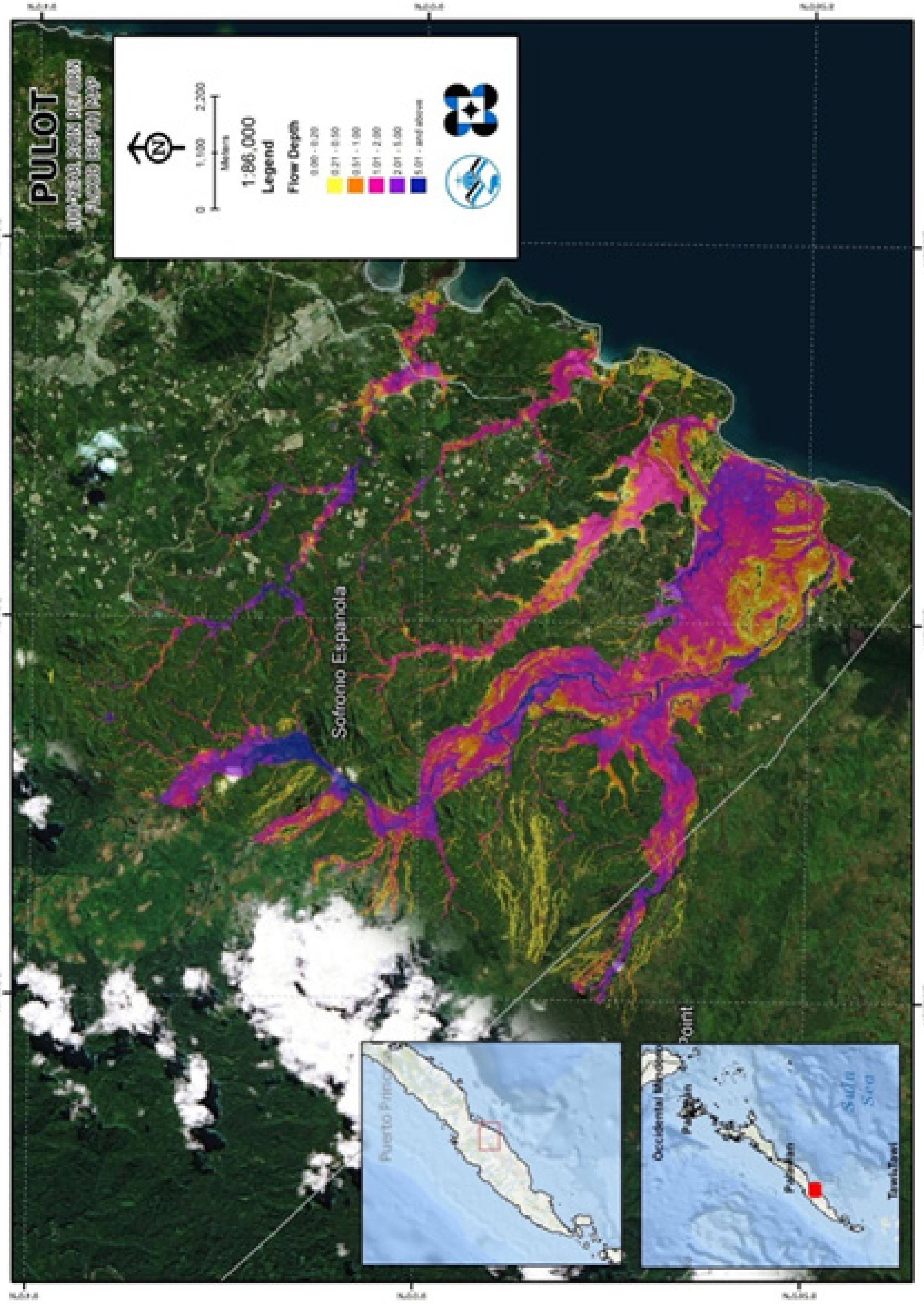

Figure 61. 100-year Flow Depth Map for Pulot Floodplain

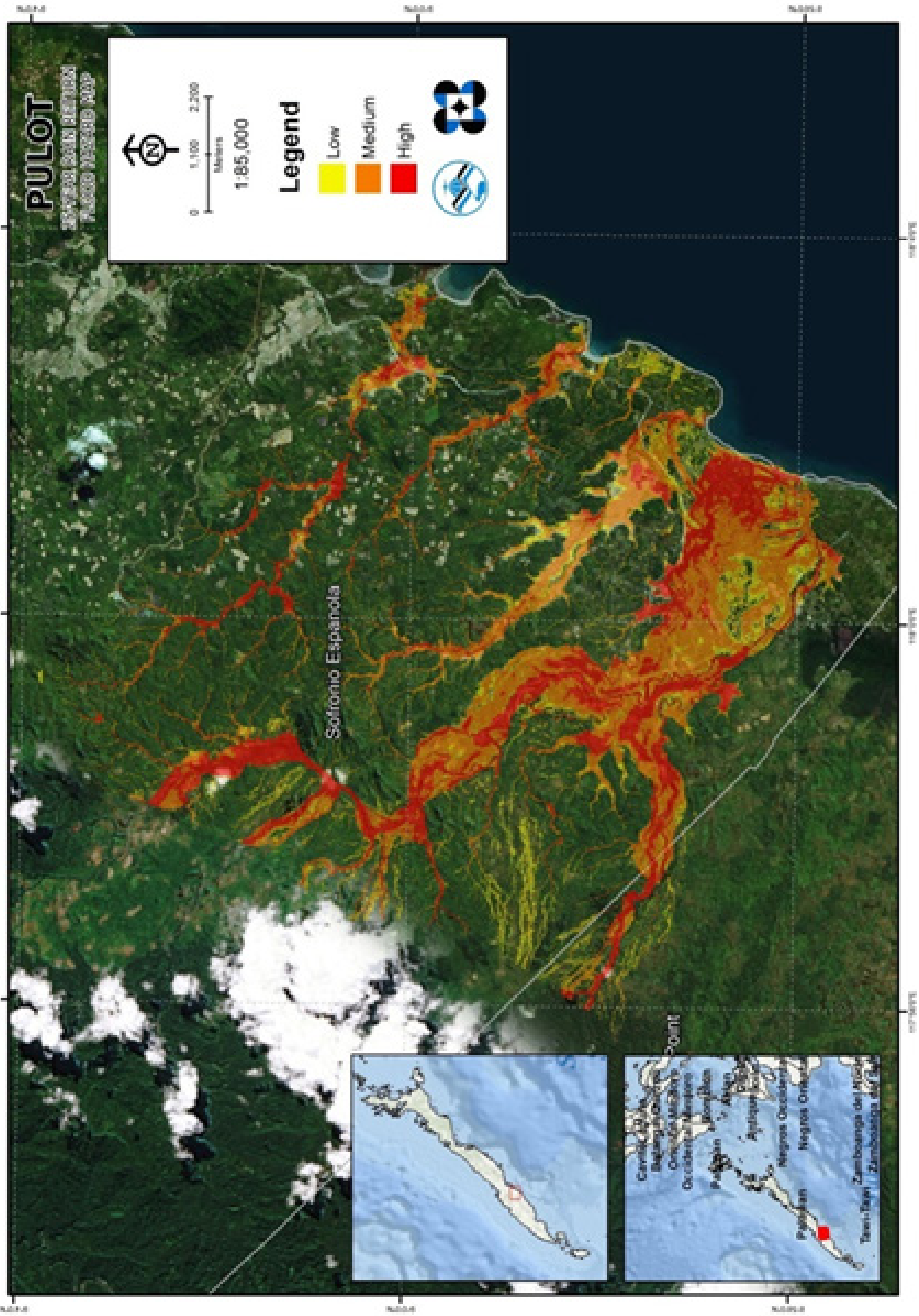

Figure 62. 25-year Flood Hazard Map for Pulot Floodplain

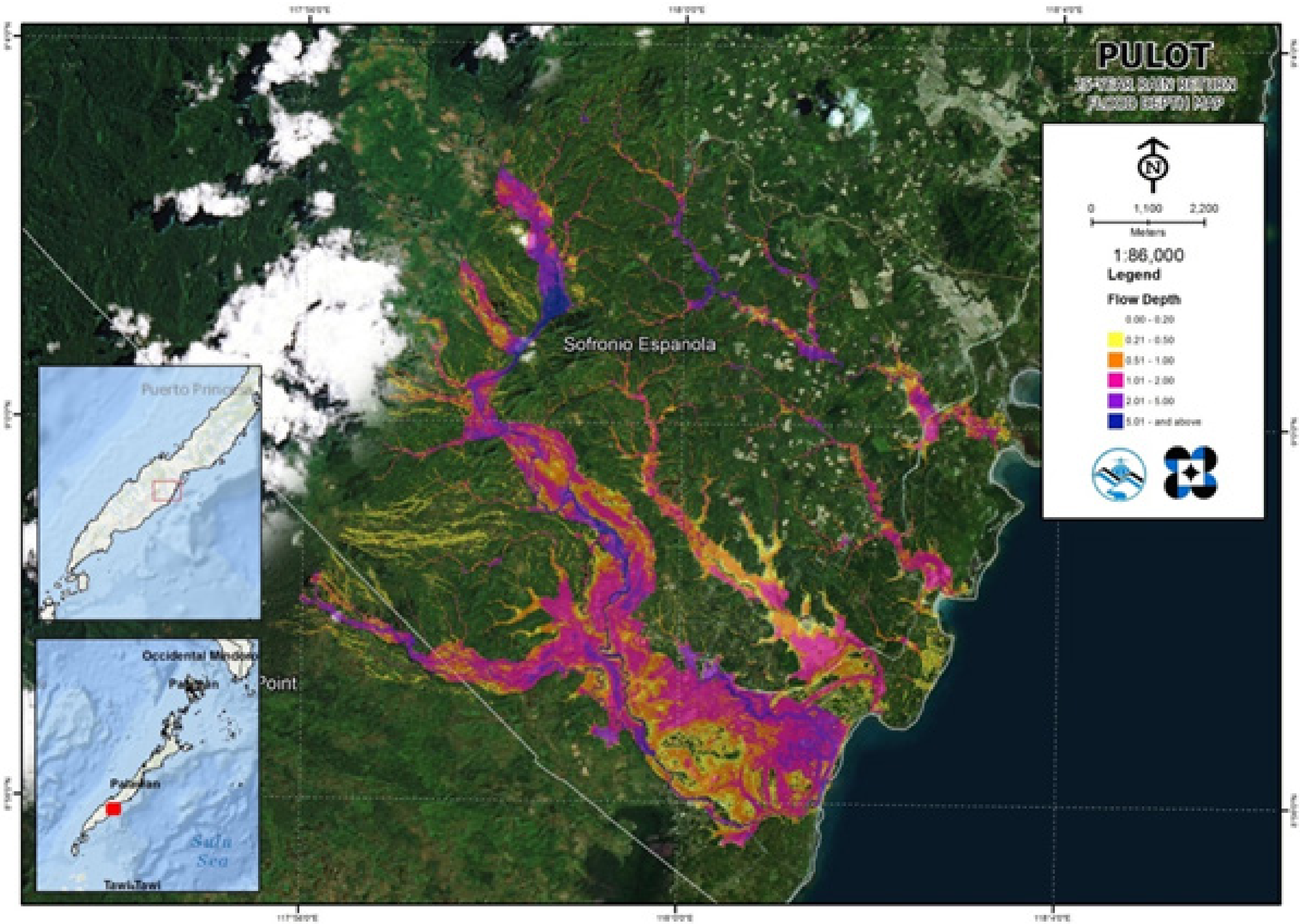

Figure 63. 25-year Flow Depth Map for Pulot Floodplain

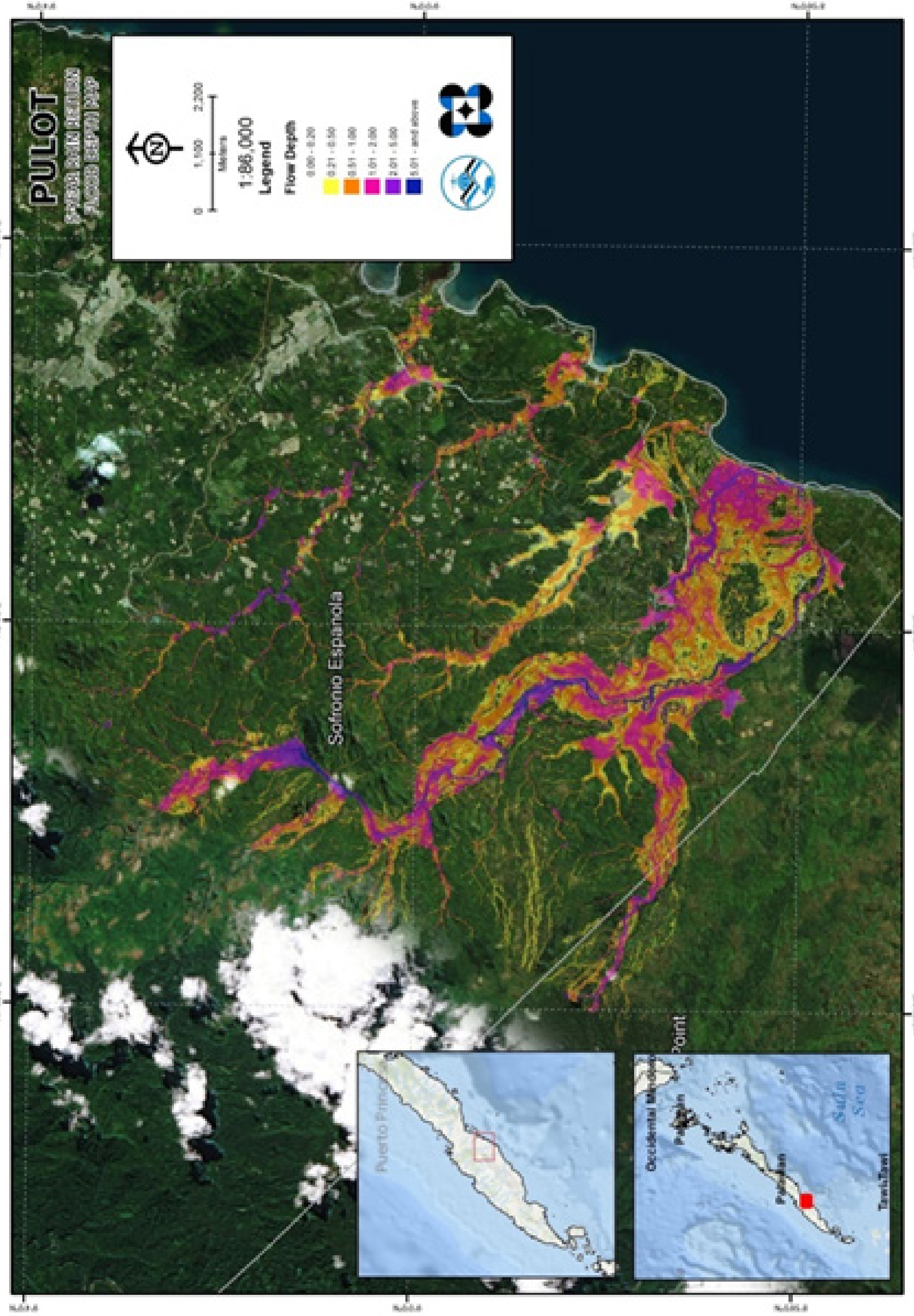

Figure 64. 5-year Flow Depth Map for Pulot Floodplain

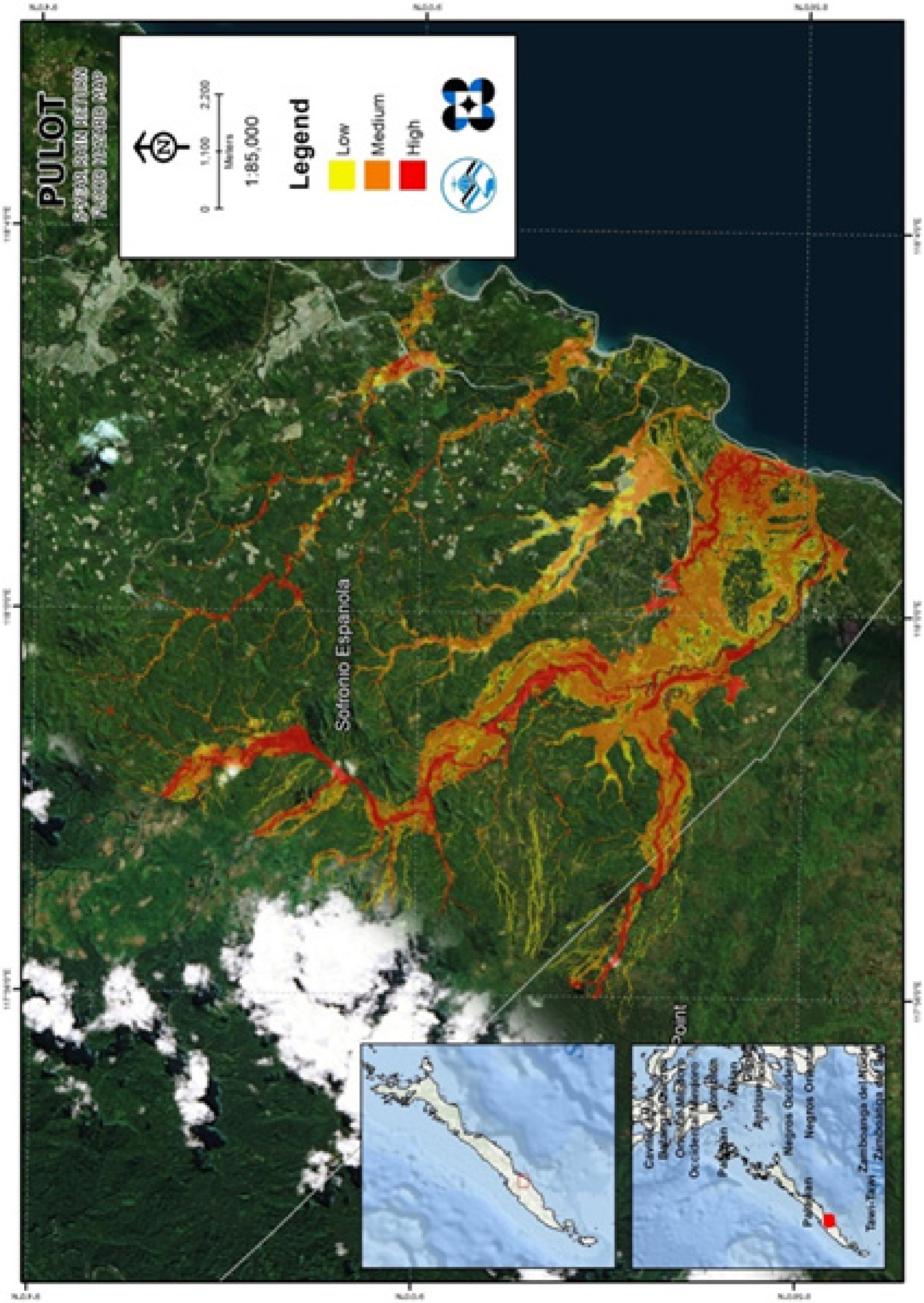

Figure 65. 5-year Flood Hazard Map for Pulot Floodplain

5.10 Inventory of Areas Exposed to Flooding

Listed below are the barangays affected by the Pulot River Basin, grouped accordingly by municipality. For the said basin, one (2) municipalities consisting of 5 barangays are expected to experience flooding when subjected to a 5-year rainfall return period.

For the 5-year return period, 0.36% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 0.05% of the area will experience flood levels of 0.21 to 0.50 meters; 0.04%, 0.03%, 0.02%, and 0.0003% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 t0 5 meters, and more than 5 meters respectively. Table 27 shows the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

Table 27. Affected areas in Brooke's Point, Palawan during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Brooke's Point
	Calasaguen
0.03-0.20	3.21
0.21-0.50	0.45
0.51-1.00	0.32
1.01-2.00	0.24
2.01-5.00	0.15
> 5.00	0.0031

Among the barangays in the municipality of Brooke's Point, Calasaguen is projected to have the highest percentage of area that will experience flood levels of at 0.49%.

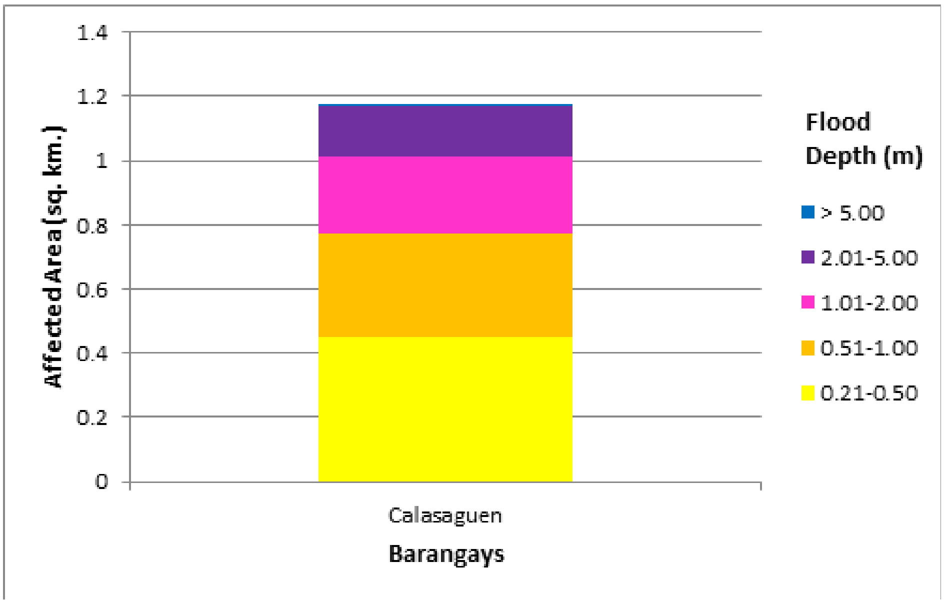

Figure 66. Affected areas in Brooke's Point, Palawan during a 5-Year Rainfall Return Period.

For the municipality of Sofronio Espanola, with an area of 477.50 sq. km., 18.23% will experience flood levels of less 0.20 meters; 1.94% of the area will experience flood levels of 0.21 to 0.50 meters while 2.43%, 1.75%, 0.56%, and 0.08% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 28 depicts the affected areas in square kilometers by flood depth per barangay.

Table 28. Affected areas in Sofronio Espanola, Palawan during a 5-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Sofronio Espanola			
	Iraray	Pulot Center	Pulot Shore	Punang
0.03-0.20	40.47	15.43	3.77	27.39
0.21-0.50	4.23	1.87	1.98	1.18
0.51-1.00	5.3	2.13	2.83	1.32
1.01-2.00	3.76	1.85	1.72	1.04
2.01-5.00	1.57	0.27	0.43	0.42
> 5.00	0.23	0.066	0.081	0.026

Among the barangays in the municipality of Sofronio Espanola, Iraray is projected to have the highest percentage of area that will experience flood levels of at 11.64%. On the other hand, Punang posted the percentage of area that may be affected by flood depths of at 6.57%.

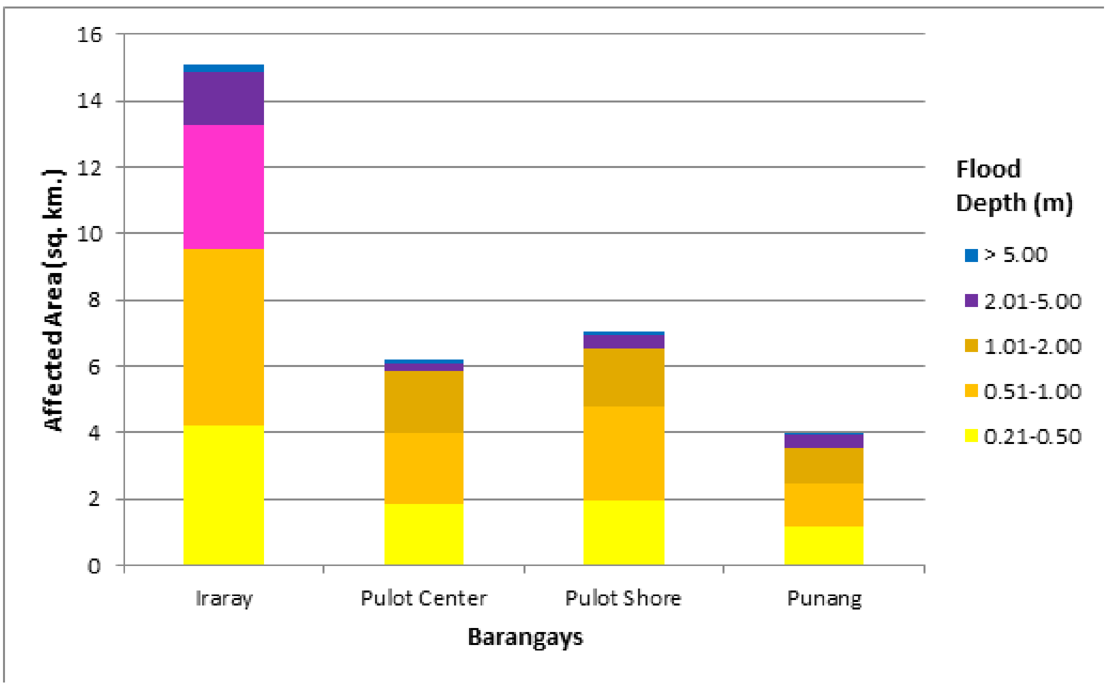

Figure 67. Areas affected by flooding in Sofronio Espanola, Palawan for a 5-Year Return Period rainfall event.

For the 25-year return period, 0.33% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 0.05% of the area will experience flood levels of 0.21 to 0.50 meters; 0.04%, 0.04%, 0.03%, and 0.002% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Table 29 depicts the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

Table 29. Affected areas in Brooke's Point, Palawan during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Brooke's Point
	Calasaguen
0.03-0.20	2.97
0.21-0.50	0.46
0.51-1.00	0.34
1.01-2.00	0.33
2.01-5.00	0.28
> 5.00	0.016

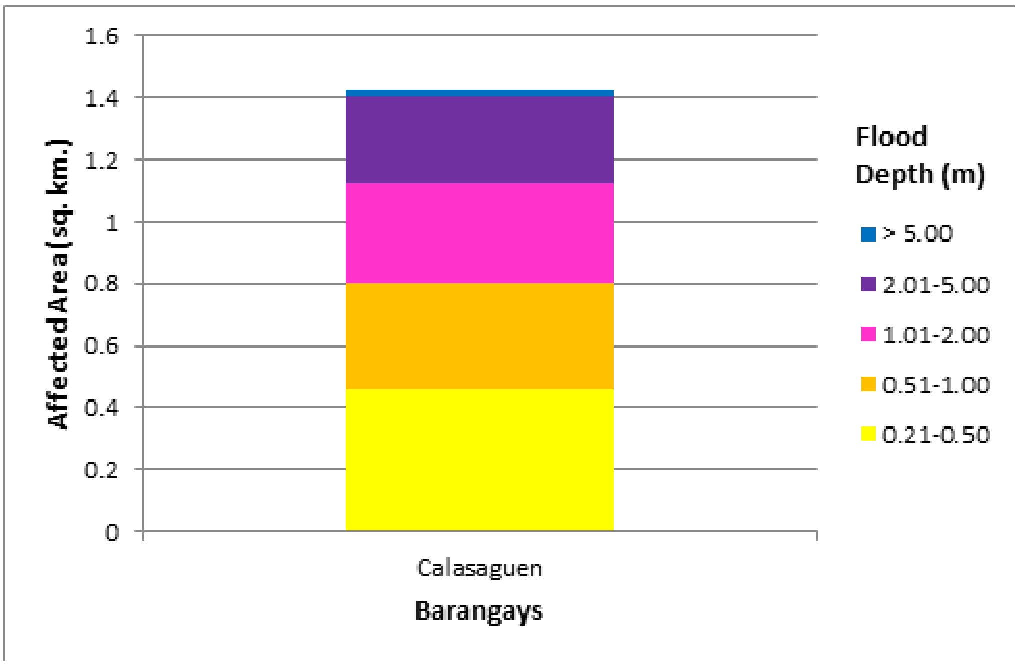

Figure 68. Affected areas in Brooke's Point, Palawan during a 25-Year Rainfall Return Period.

For the municipality of Sofronio Espanola, with an area of 477.50 sq. km., 17.15% will experience flood levels of less 0.20 meters; 1.60% of the area will experience flood levels of 0.21 to 0.50 meters while 2.22%, 2.85%, 1.01%, and 0.17% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 30 depicts the affected areas in square kilometers by flood depth per barangay.

Table 30. Affected areas in Sofronio Espanola, Palawan during a 25-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Sofronio Espanola			
	Iraray	Pulot Center	Pulot Shore	Punang
0.03-0.20	38.13	14.51	2.55	26.7
0.21-0.50	3.39	1.75	1.43	1.06
0.51-1.00	4.86	1.77	2.7	1.27
1.01-2.00	5.96	2.9	3.24	1.53
2.01-5.00	2.65	0.62	0.81	0.72
> 5.00	0.58	0.069	0.085	0.085

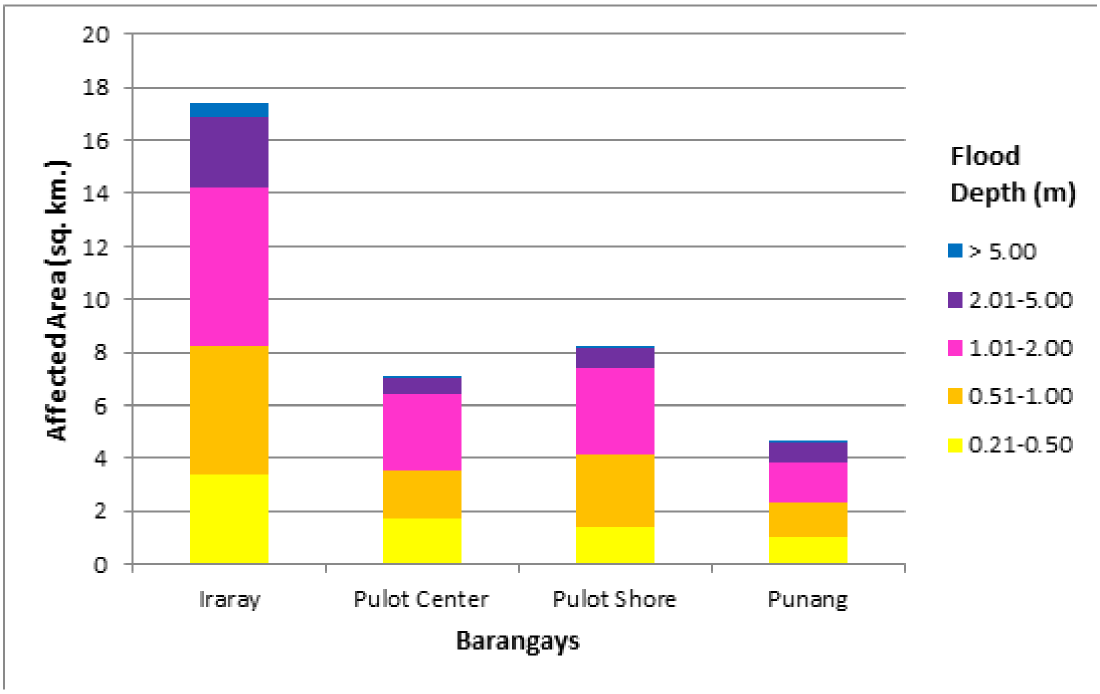

Figure 69. Areas affected by flooding in Sofronio Espanola, Palawan for a 25-Year Return Period rainfall event.

For the 100-year return period, 0.32% of the municipality of Brooke's Point with an area of 893.39 sq. km. will experience flood levels of less 0.20 meters, while 0.05% of the area will experience flood levels of 0.21 to 0.50 meters; 0.04%, 0.04%, 0.04%, and 0.004% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters respectively. Table 31 depicts the areas affected in Brooke's Point in square kilometers by flood depth per barangay.

Table 31. Affected areas in Brooke's Point, Palawan during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Brooke's Point
	Calasaguen
0.03-0.20	2.83
0.21-0.50	0.48
0.51-1.00	0.33
1.01-2.00	0.35
2.01-5.00	0.37
> 5.00	0.037

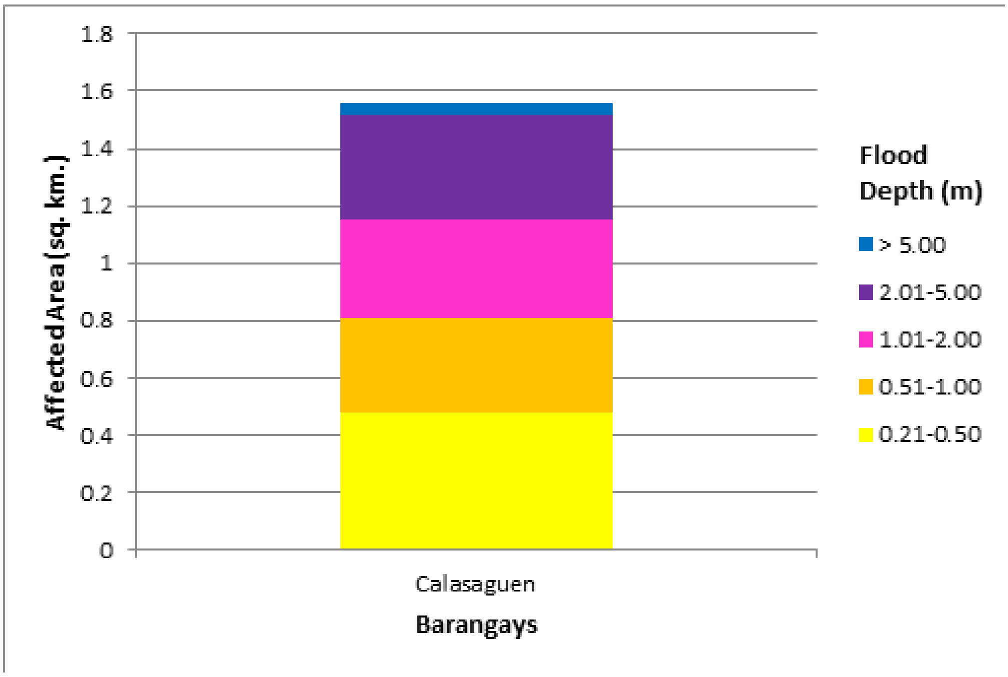

Figure 70. Affected areas in Brooke's Point, Palawan during a 100-Year Rainfall Return Period.

For the municipality of Sofronio Espanola, with an area of 477.50 sq. km., 16.66% will experience flood levels of less 0.20 meters. 1.46% of the area will experience flood levels of 0.21 to 0.50 meters while 1.98%, 3.21%, 1.44%, and 0.25% of the area will experience flood depths of 0.51 to 1 meter, 1.01 to 2 meters, 2.01 to 5 meters, and more than 5 meters, respectively. Table 32 depicts the affected areas in square kilometers by flood depth per barangay.

Table 32. Affected areas in Sofronio Espanola, Palawan during a 100-Year Rainfall Return Period.

Affected Area (sq. km.) by flood depth (in m.)	Affected Barangays in Sofronio Espanola			
	Iraray	Pulot Center	Pulot Shore	Punang
0.03-0.20	37.03	14.01	2.15	26.34
0.21-0.50	3.12	1.79	1	1.04
0.51-1.00	4.31	1.46	2.54	1.17
1.01-2.00	6.81	3.01	3.76	1.75
2.01-5.00	3.42	1.27	1.27	0.93
> 5.00	0.89	0.07	0.087	0.15

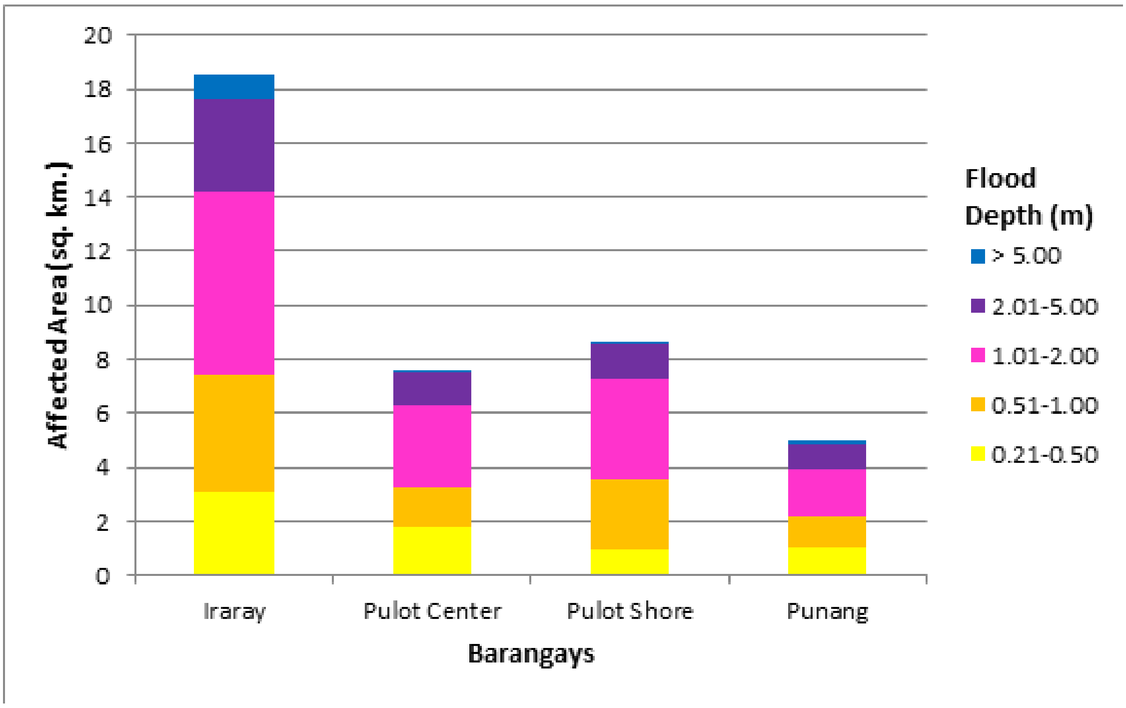

Figure 71. Areas affected by flooding in Sofronio Espanola, Palawan for a 100-Year Return Period rainfall event.

Among the barangays in the municipality of Brooke's Point, only Calasaguen is projected to experience flood levels at 0.49%.

Among the barangays in the municipality of Sofronio Espanola, Iraray is projected to have the highest percentage of area that will experience flood levels at 11.64%. Meanwhile, Punangposted the second highest percentage of area that may be affected by flood depths at 6.57%.

5.11 Flood Validation

In order to check and validate the extent of flooding in different river systems, there is a need to perform validation survey work. Field personnel gathered secondary data regarding flood occurrence in the area within the major river system in the Philippines.

From the Flood Depth Maps produced by Phil-LiDAR 1 Program, multiple points representing the different flood depths for different scenarios were identified for validation.

The validation personnel went to the specified points identified in a river basin and gathered data regarding the actual flood level in each location. Data gathering was done through a local DRRM office to obtain maps or situation reports about the past flooding events or interview some residents with knowledge of or have had experienced flooding in a particular area.

After which, the actual data from the field will be compared to the simulated data to assess the accuracy of the Flood Depth Maps produced and to improve on what is needed. The points in the flood map versus its corresponding validation depths are shown in Figure 73.

The flood validation consists of 76 points randomly selected all over the Pulot floodplain. Comparing it with the flood depth map of the nearest storm event, the map has an RMSE value of 0.816m. Table 34 shows a contingency matrix of the comparison.

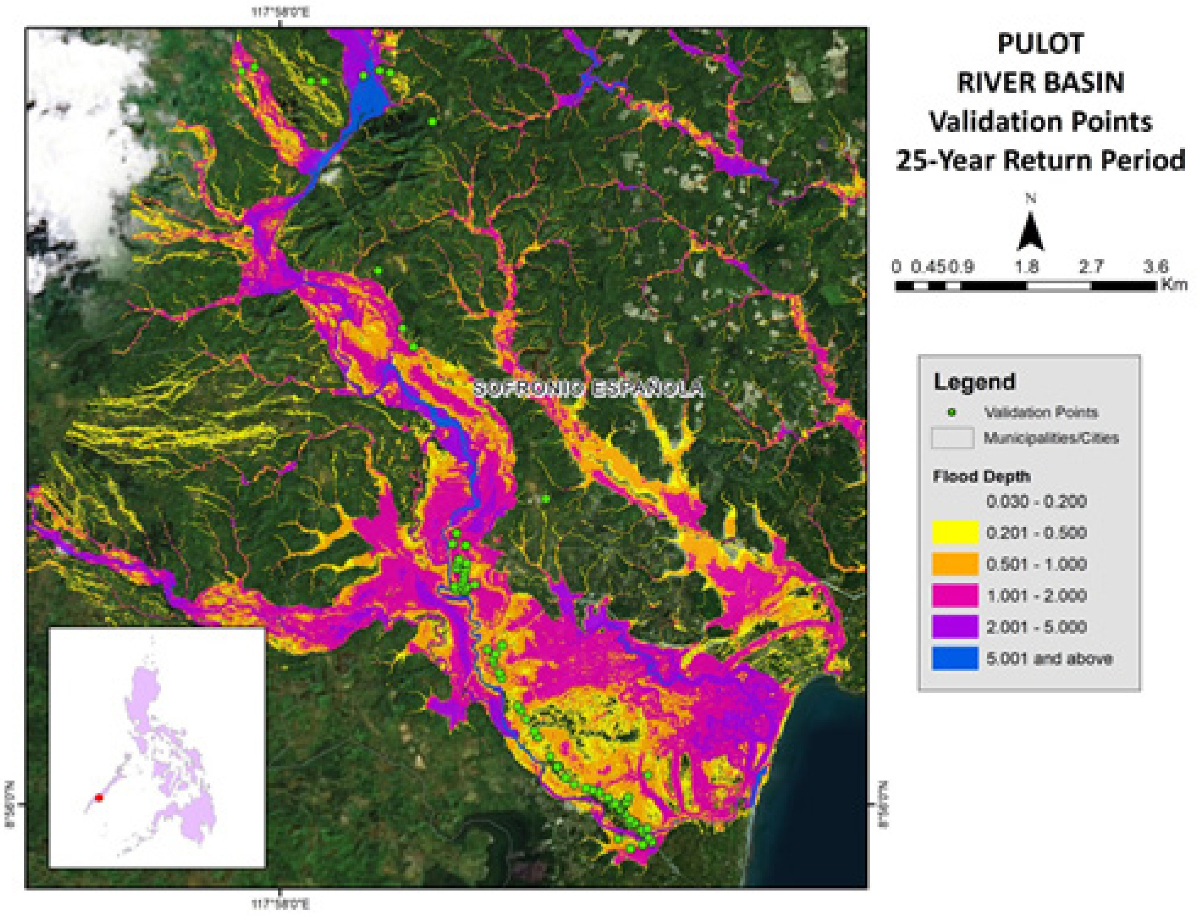

Figure 72. Validation points for 25-year Flood Depth Map of Pulot Floodplain

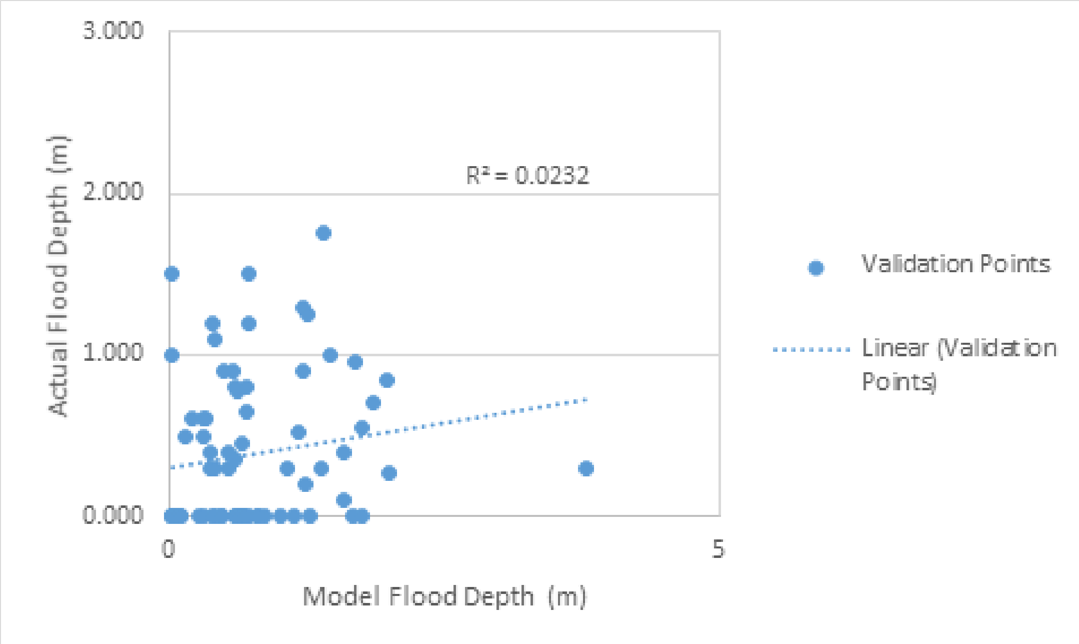

Figure 73. Flood map depth vs actual flood depth

Table 33. Actual flood versus simulated flood depth in the Pulot River Basin

Actual Flood Depth (m)	Modeled Flood Depth (m)						
	0-0.20	0.21-0.50	0.51-1.00	1.01-2.00	2.01-5.00	> 5.00	Total
0-0.20	10	6	15	6	0	0	37
0.21-0.50	1	4	4	4	1	0	14
0.51-1.00	2	3	5	7	0	0	17
1.01-2.00	1	2	2	3	0	0	8
2.01-5.00	0	0	0	0	0	0	0
> 5.00	0	0	0	0	0	0	0
Total	14	15	26	20	1	0	76

The overall accuracy generated by the flood model is estimated at 28.95% with 22 points correctly matching the actual flood depths. In addition, there were 20 points estimated one level above and below the correct flood depths while there were 23 points and 8 points estimated two levels above and below, and three or more levels above and below the correct flood. A total of 4 points were overestimated while a total of 11 points were underestimated in the modeled flood depths of Pulot. Table 38 depicts the summary of the Accuracy Assessment in the Pulot River Basin Survey.

Table 34. Summary of Accuracy Assessment in the Pulot River Basin Survey

	No. of Points	%
Correct	22	28.95
Overestimated	43	56.58
Underestimated	11	14.47
Total	76	100.00

REFERENCES

Ang M.O., Paringit E.C., et al. 2014. DREAM Data Processing Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

Balicanta L.P., Paringit E.C., et al. 2014. DREAM Data Validation Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

Brunner, G. H. 2010a. HEC-RAS River Analysis System Hydraulic Reference Manual. Davis, CA: U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center.

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Paringit E.C, Balicanta L.P., Ang, M.O., Sarmiento, C. 2017. Flood Mapping of Rivers in the Philippines Using Airborne Lidar: Methods. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

Sarmiento C., Paringit E.C., et al. 2014. DREAM Data Acquisition Component Manual. Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

UP TCAGP 2016, Acceptance and Evaluation of Synthetic Aperture Radar Digital Surface Model (SAR DSM) and Ground Control Points (GCP). Quezon City, Philippines: UP Training Center for Applied Geodesy and Photogrammetry.

ANNEXES

Annex 1. Technical Specifications of the Gemini Sensors used in the Pulot Floodplain Survey

Figure A-1.1 Gemini Sensor

Table A-1.1 Parameters and Specifications of the Gemini Sensor

Parameter	Specification
Operational envelope (1,2,3,4)	150-4000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, (m AGL)
Elevation accuracy (2)	<5-35 cm, 1 σ
Effective laser repetition rate	Programmable, 33-167 kHz
Position and orientation system	POS AV™ AP50 (OEM);
220-channel dual frequency GPS/GNSS/Galileo/L-Band receiver	Programmable, 0-75 ˚
Scan width (WOV)	Programmable, 0-50˚
Scan frequency (5)	Programmable, 0-70 Hz (effective)
Sensor scan product	1000 maximum
Beam divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Roll compensation	Programmable, ±5˚ (FOV dependent)
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Video Camera	Internal video camera (NTSC or PAL)
Image capture	Compatible with full Optech camera line (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer (optional)
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V; 900 W;35 A(peak)
Dimensions and weight	Sensor: 260 mm (w) x 190 mm (l) x 570 mm (h); 23 kg
Control rack: 650 mm (w) x 590 mm (l) x 530 mm (h); 53 kg	-10°C to +35°C
Operating temperature	-10˚C to +35˚C (with insulating jacket)
Relative humidity	0-95% no-condensing

Annex 2. NAMRIA Certification of Reference Points Used in the LIDAR Survey

Republic of the Philippines
Department of Environment and Natural Resources
NATIONAL MAPPING AND RESOURCE INFORMATION AUTHORITY

July 21, 2015

CERTIFICATION

To whom it may concern:

This is to certify that according to the records on file in this office, the requested survey information is as follows -

Province: **PALAWAN**
Station Name: **PLW-13**
Order: **2nd**

Island: **LUZON**
Municipality: **PUERTO PRINCESA CITY (CAPITAL)**
Barangay: **RIO TUBA**
MSL Elevation:

	PRS92 Coordinates	
Latitude: **8° 30' 17.42901"**	Longitude: **117° 25' 55.42672"**	Ellipsoidal Hgt: **-0.25567 m.**
	WGS84 Coordinates	
Latitude: **8° 30' 13.19373"**	Longitude: **117° 26' 0.86501"**	Ellipsoidal Hgt: **49.35000 m.**
	PTM / PRS92 Coordinates	
Northing: **940540.844 m.**	Easting: **382414.126 m.**	Zone: **1A**
	UTM / PRS92 Coordinates	
Northing: **940,076.76**	Easting: **547,553.57**	Zone: **50**

Location Description

PLW-13
From Puerto Princesa travel along the National Highway for 249.2 ikilometers, about 4 hours and 15 minutes drive to Rio Tuba Nickel iMining Corporation. Thence travel south direction for 4.7 ikilometers or 5 minutes drive, then turn right going West idirection for 300 meters up to barangay Rio Tuba. The station is ilocated on a big boulder in the pier site; 70 meters North of ibarangay captain's house. Station mark is a cross cut of 0.15 m x i0.01 m in diameter brass rod, set in a drill hole centered in a i30 cm x 30 cm cement patty on big boulder. Inscribed on top with ithe station name. All reference mark numbers 1,2,3 and 4 are icross cut on top of brass rods, set in a drill hole on big iboulder, centered in a 25 cm x 25 cm cement patty, and inscribed iwith the station name and arrows pointing to the station.

Requesting Party:	**ENGR. CHRISTOPHER CRUZ**
Purpose:	**Reference**
OR Number:	**8086767 I**
T.N.:	**2015-1694**

RUEL DM. BELEN, MNSA
Director, Mapping And Geodesy Branch

NAMRIA OFFICES
Main : Lawton Avenue, Fort Bonifacio, 1634 Taguig City, Philippines Tel. No.: (632) 810-4831 to 41
Branch : 421 Barraca St. San Nicolas, 1010 Manila, Philippines, Tel. No. (632) 241-3494 to 98
www.namria.gov.ph

ISO 9001: 2008 CERTIFIED FOR MAPPING AND GEOSPATIAL INFORMATION MANAGEMENT

Figure A-2.1 PLW-13

Annex 3. Baseline Processing Reports of Reference Points Used

Vector Components (Mark to Mark)

From:	PLW-3058				
Grid		Local		Global	
Easting	-47262.004 m	Latitude	N8°57'34.41133"	Latitude	N8°57'30.11407"
Northing	994023.986 m	Longitude	E118°01'39.35197"	Longitude	E118°01'44.74876"
Elevation	-3.131 m	Height	-2.948 m	Height	47.207 m

To:	PL-412				
Grid		Local		Global	
Easting	-44042.610 m	Latitude	N9°01'08.45200"	Latitude	N9°01'04.14225"
Northing	1000578.048 m	Longitude	E118°03'21.49607"	Longitude	E118°03'26.88749"
Elevation	-0.491 m	Height	-0.337 m	Height	49.765 m

Vector					
ΔEasting	3219.394 m	NS Fwd Azimuth	25°22'54"	ΔX	-2271.764 m
ΔNorthing	6554.062 m	Ellipsoid Dist.	7278.148 m	ΔY	-2371.208 m
ΔElevation	2.640 m	ΔHeight	2.612 m	ΔZ	6495.211 m

Standard Errors

Vector errors:					
σ ΔEasting	0.002 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.005 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.002 m	σ ΔY	0.008 m
σ ΔElevation	0.009 m	σ ΔHeight	0.009 m	σ ΔZ	0.002 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000235182		
Y	-0.0000351146	0.0000644168	
Z	-0.0000050329	0.0000098915	0.0000055951

Figure A-3.1 PL-412

Vector Components (Mark to Mark)

From:	PLW-13				
Grid		Local		Global	
Easting	-113741.490 m	Latitude	N8°30'17.42900"	Latitude	N8°30'13.19373"
Northing	944471.057 m	Longitude	E117°25'55.42676"	Longitude	E117°26'00.86501"
Elevation	1.573 m	Height	-0.256 m	Height	49.350 m

To:	PLW-3058				
Grid		Local		Global	
Easting	-47262.005 m	Latitude	N8°57'34.41144"	Latitude	N8°57'30.11418"
Northing	994023.989 m	Longitude	E118°01'39.35193"	Longitude	E118°01'44.74872"
Elevation	-3.162 m	Height	-2.979 m	Height	47.176 m

Vector					
ΔEasting	66479.484 m	NS Fwd Azimuth	52°27'10"	ΔX	-54449.894 m
ΔNorthing	49552.932 m	Ellipsoid Dist.	82603.650 m	ΔY	-37251.571 m
ΔElevation	-4.735 m	ΔHeight	-2.724 m	ΔZ	49706.928 m

Standard Errors

Vector errors:					
σ ΔEasting	0.003 m	σ NS fwd Azimuth	0°00'00"	σ ΔX	0.006 m
σ ΔNorthing	0.002 m	σ Ellipsoid Dist.	0.003 m	σ ΔY	0.011 m
σ ΔElevation	0.012 m	σ ΔHeight	0.012 m	σ ΔZ	0.003 m

Aposteriori Covariance Matrix (Meter²)

	X	Y	Z
X	0.0000356543		
Y	-0.0000566784	0.0001191653	
Z	-0.0000106477	0.0000187894	0.0000078497

Figure A-3.2 PW-3058

Annex 4. The LiDAR Survey Team Composition

Table A-4.1. The LiDAR Survey Team Composition

Data Acquisition Component Sub -Team	Designation	Name	Agency / Affiliation
PHIL-LIDAR 1	Program Leader	ENRICO C. PARINGIT, D.ENG	UP-TCAGP
Data Acquisition Component Leader	Data Component Project Leader – I	ENGR. LOUIE BALICANTA	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP-TCAGP
LiDAR Operation	Supervising Science Research Specialist (Supervising SRS)	LOVELY GRACIA ACUÑA	UP-TCAGP
		LOVELYN ASUNCION	UP-TCAGP

FIELD TEAM

LiDAR Operation	Senior Science Research Specialist (SSRS)	GEROME HIPOLITO	UP-TCAGP
	Research Associate (RA)	MARY CATHERINE ELIZABETH BALIGUAS	UP-TCAGP
		JONATHAN ALMALVEZ	UP-TCAGP
Ground Survey, Data Download and Transfer	RA	ENGR. IRO NIEL ROXAS	UP-TCAGP
LiDAR Operation	Airborne Security	SSG. PRADYUMNA DAS RAMIREZ	PHILIPPINE AIR FORCE (PAF)
		AT2C JUNMAR PARANGUE	PAF
	Pilot	CAPT. MARK TANGONAN	ASIAN AEROSPACE CORPORATION (AAC)
		CAPT. ALBERT PAUL LIM	AAC
		CAPT. RANDY LAGCO	AAC

Annex 5. Data Transfer Sheet for Pulot Floodplain

DATA TRANSFER SHEET
PALAWAN 12/17/15

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS(MB)	POS	RAW IMAGES/CASI	MISSION LOG FILE/CASI LOGS	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
20-Nov-15	3565	2BLK42PQR337A	GEMINI	NA	92	535	202	na	na	25.4	na	6.96	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
21-Nov-15	3571	2BLK42Tv338A	GEMINI	NA	171	370	160	na	na	14.6	na	640	1KB	1KB	22/24/22/48/51	NA	Z:\DAC\RAW DATA
26-Nov-15	3573	2BLK42Ov339A	GEMINI	NA	484	1	227	na	na	19.7	na	12.1	1KB	1KB	24/22/48/53/51/30	NA	Z:\DAC\RAW DATA
27-Nov-15	3575	2BLK42OQ339B	GEMINI	NA	734	530	218	na	na	22.3	na	12.1	1KB	1KB	24/22/30/53/50/48/51	NA	Z:\DAC\RAW DATA
28-Nov-15	3581	2BLK42NPQ341A	GEMINI	NA	872	484	232	na	na	21.2	na	8.55	1KB	NA	24/22/21/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3585	2BLK42Nv342A	GEMINI	NA	1080	558	234	na	na	23	na	5.29	1KB	1KB	24/22/21/28/27/30/53/50/48/51	NA	Z:\DAC\RAW DATA
30-Nov-15	3593	2BLK42TwEwF344A	GEMINI	NA	1343	523	227	na	na	20.9	na	11.4	1KB	1KB	53/50/48/17	NA	Z:\DAC\RAW DATA
1-Dec-15	3595	2BLK42US344B	GEMINI	NA	253	387	156	na	na	17.4	na	11.4	1KB	1KB	17/16	NA	Z:\DAC\RAW DATA

Received from
Name [illegible]
Position
Signature

Received by
Name AC Bongat
Position SSRS
Signature 1/5/2016

Figure A-5.1. Transfer Sheet for Pulot Floodplain

Annex 6. Flight Logs for the Flight Missions

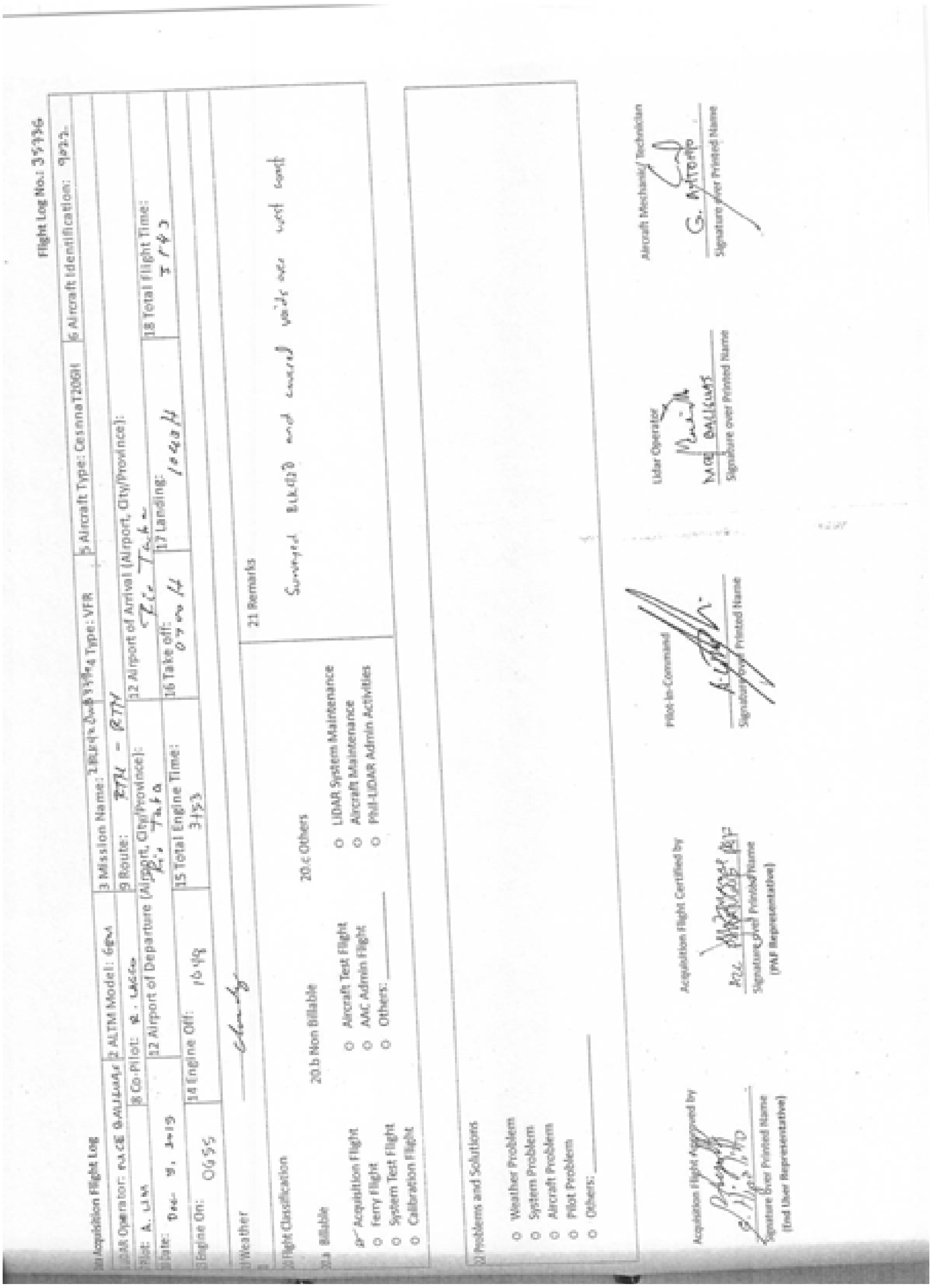
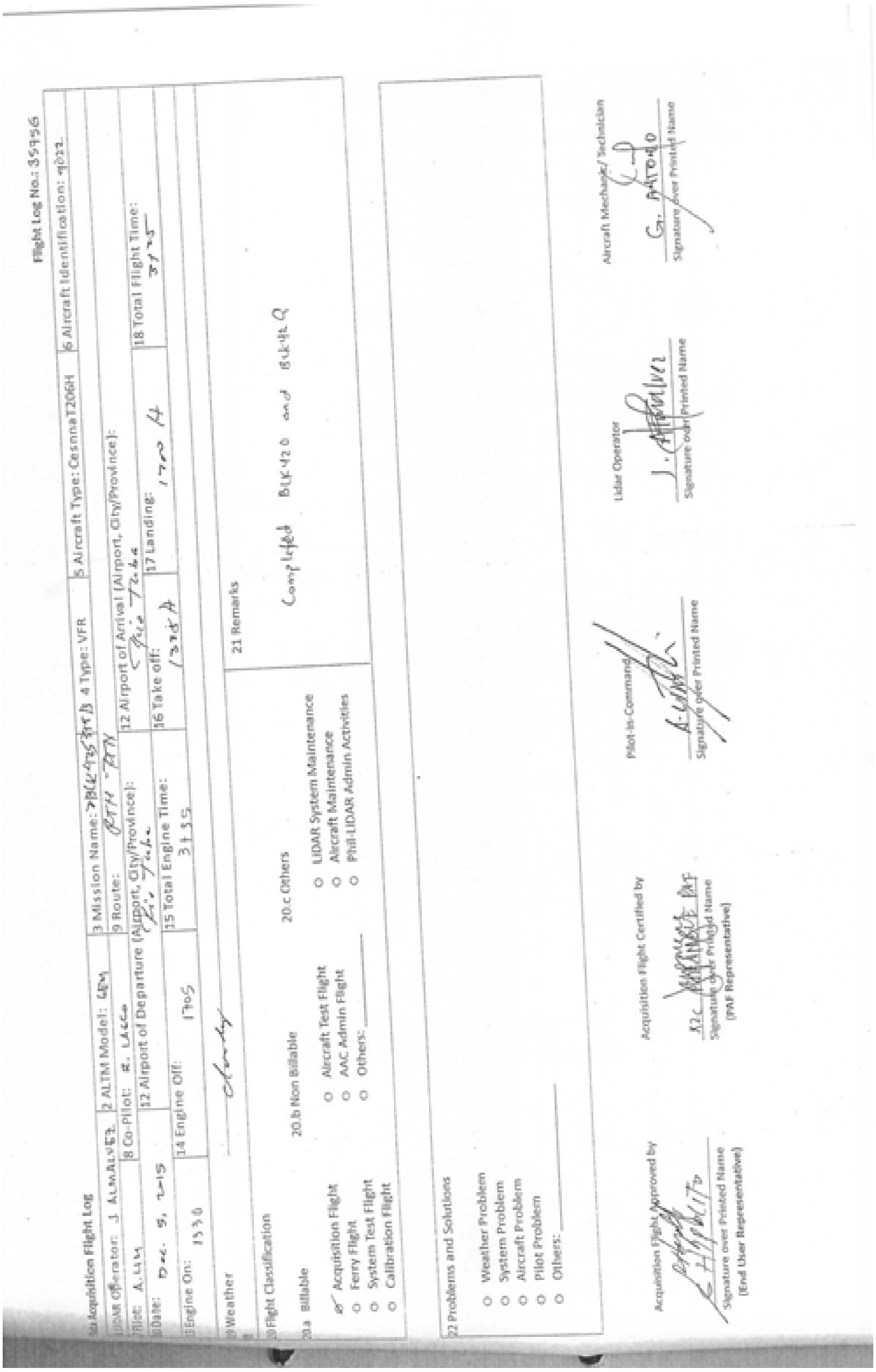


Figure A-6.1 Flight Log for 3573G Mission



Flight Log No.: 3575G

1 LiDAR Operator: J. ALMALVEZ | 2 ALTM Model: GEM | 3 Mission Name: 2BLK42S575B | 4 Type: VFR | 5 Aircraft Type: CesnnaT206H | 6 Aircraft Identification: 9022

7 Pilot: A. LIM | 8 Co-Pilot: R. LAGCO | 9 Route: PPN - PPN

10 Date: Dec. 5, 2015 | 12 Airport of Departure (Airport, City/Province): Puerto Princesa | 12 Airport of Arrival (Airport, City/Province): Puerto Princesa

13 Engine On: 1330 | 14 Engine Off: 1705 | 15 Total Engine Time: 3+35 | 16 Take off: 1335H | 17 Landing: 1700H | 18 Total Flight Time: 3+25

19 Weather: cloudy

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- ○ Ferry Flight
- ○ System Test Flight
- ○ Calibration Flight

20.b Non Billable
- ○ Aircraft Test Flight
- ○ AAC Admin Flight
- ○ Others: ____

20.c Others
- ○ LIDAR System Maintenance
- ○ Aircraft Maintenance
- ○ Phil-LIDAR Admin Activities

21 Remarks

Completed BLK42O and BLK42Q

22 Problems and Solutions
- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ____

Acquisition Flight Approved by: C. HIPOLITO — Signature over Printed Name (End User Representative)

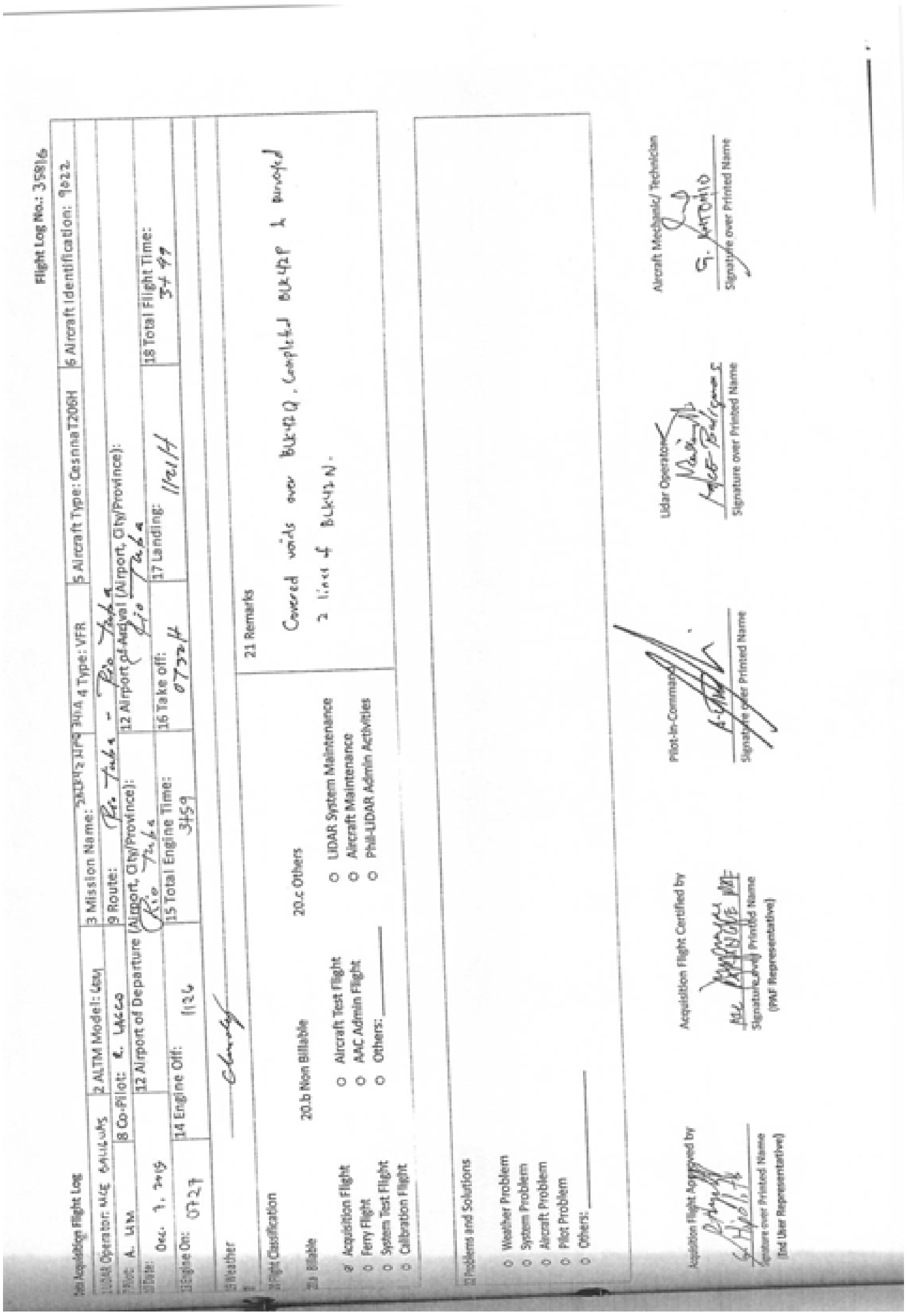
Acquisition Flight Certified by: S2C [illegible] PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: A. LIM — Signature over Printed Name

Lidar Operator: J. ALMALVEZ — Signature over Printed Name

Aircraft Mechanic/ Technician: G. ANTONIO — Signature over Printed Name

Figure A-6.2 Flight Log for 3575G Mission



Data Acquisition Flight Log

Flight Log No.: 3581G

1 LiDAR Operator:	2 ALTM Model:	3 Mission Name:	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9022
7 Pilot: A. Lim	8 Co-Pilot:	9 Route: Rio Tuba - Rio Tuba			
10 Date: Oct. 7, 2015	12 Airport of Departure (Airport, City/Province): Rio Tuba		12 Airport of Arrival (Airport, City/Province): Rio Tuba		
13 Engine On: 0727	14 Engine Off: 1126	15 Total Engine Time: 3+59	16 Take off: 0732H	17 Landing: 1121H	18 Total Flight Time: 3+49

19 Weather: Cloudy

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- ○ Ferry Flight
- ○ System Test Flight
- ○ Calibration Flight

20.b Non Billable
- ○ Aircraft Test Flight
- ○ AAC Admin Flight
- ○ Others: ____

20.c Others
- ○ LiDAR System Maintenance
- ○ Aircraft Maintenance
- ○ Phil-LiDAR Admin Activities

21 Remarks

Covered voids over BLK42Q. Completed BLK42P & surveyed 2 lines of BLK42N.

22 Problems and Solutions
- ○ Weather Problem
- ○ System Problem
- ○ Aircraft Problem
- ○ Pilot Problem
- ○ Others: ____

Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

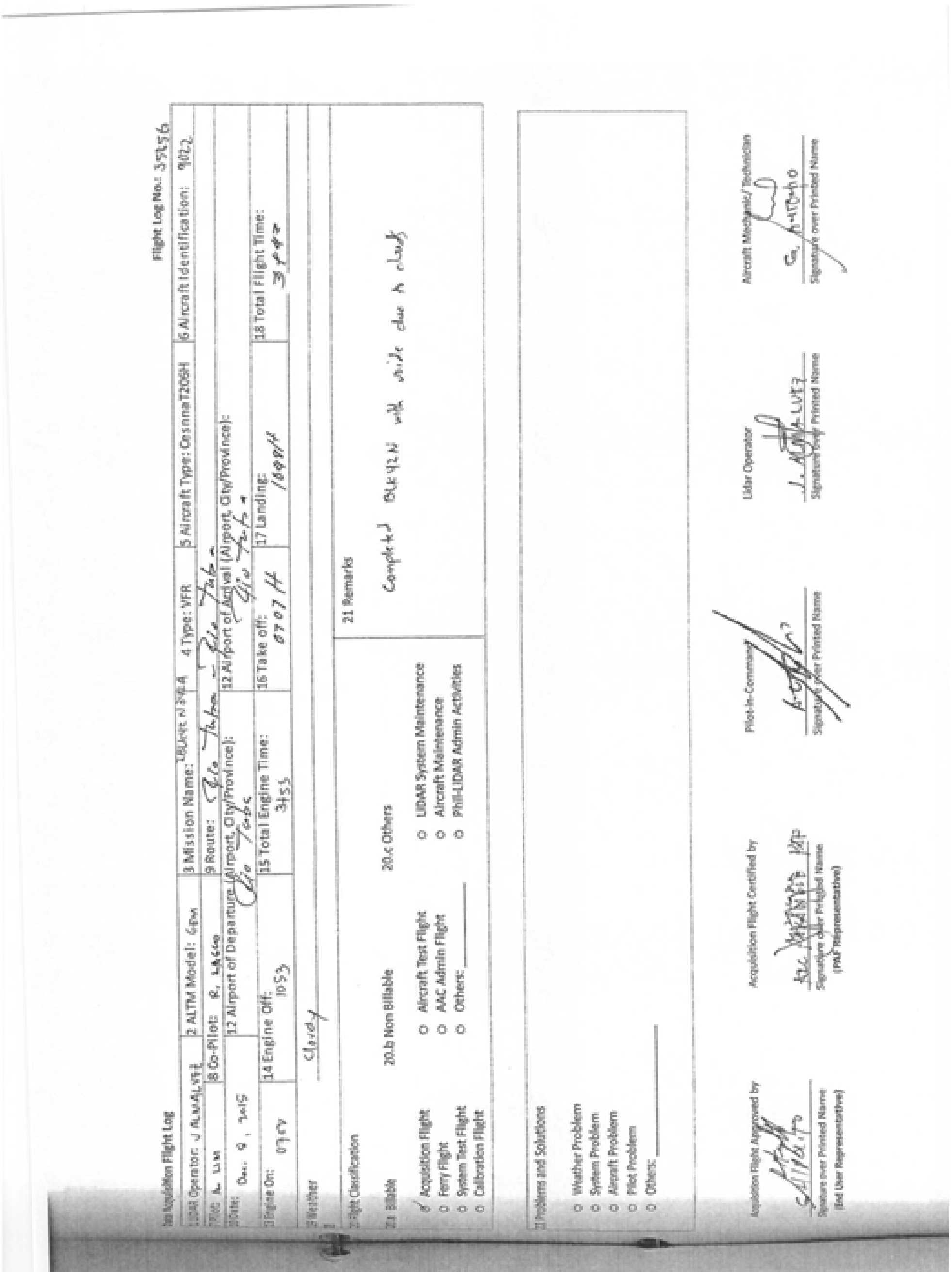
Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

Aircraft Mechanic/ Technician — Signature over Printed Name

Figure A-6.3. Flight Log for 3581G Mission



Flight Log No.: 3585G

1 LiDAR Operator: J. ALMALVEZ | 2 ALTM Model: Gem | 3 Mission Name: 1BLK42N 342A | 4 Type: VFR | 5 Aircraft Type: Cessna T206H | 6 Aircraft Identification: 9022

7 Pilot: A. Lim | 8 Co-Pilot: R. Lacco | 9 Route: Iloilo Tabon - Iloilo Tabon

10 Date: Dec. 9, 2015 | 12 Airport of Departure (Airport, City/Province): Iloilo Tabon | 12 Airport of Arrival (Airport, City/Province): Iloilo Tabon

13 Engine On: 0704 | 14 Engine Off: 1053 | 15 Total Engine Time: 3+53 | 16 Take off: 0707 H | 17 Landing: 1050H | 18 Total Flight Time: 3+43

19 Weather: Cloudy

20 Flight Classification

20.a Billable
- ✓ Acquisition Flight
- Ferry Flight
- System Test Flight
- Calibration Flight

20.b Non Billable
- Aircraft Test Flight
- AAC Admin Flight
- Others: ____

20.c Others
- LiDAR System Maintenance
- Aircraft Maintenance
- Phil-LiDAR Admin Activities

21 Remarks

Completed BLK42N with voids due to clouds

22 Problems and Solutions
- Weather Problem
- System Problem
- Aircraft Problem
- Pilot Problem
- Others: ____

Acquisition Flight Approved by: Signature over Printed Name (End User Representative)

Acquisition Flight Certified by: Signature over Printed Name (PAF Representative)

Pilot-in-Command: Signature over Printed Name

Lidar Operator: J. ALMALVEZ — Signature over Printed Name

Aircraft Mechanic/ Technician: Signature over Printed Name

Figure A-6.4 Flight Log for 3585G Mission

Annex 7. Flight Status

Table A-7.1. Flight Status Report

PALAWAN REFLIGHTS
(November 12 to December 12, 2015)

FLIGHT NO	AREA	MISSION	OPERATOR	DATE FLOWN	REMARKS
3573G	BLK 42eO; 42L; 42M	2BLK42Ov339A	MCE Baliguas	December 5, 2015	Surveyed BLK42eO and west voids (BLK42L,M)
3575G	BLK 42eO; 42eQ	2BLK42OQ339B	JM Almalvez	December 5, 2015	Surveyed BLK42eO, 42eQ. 42eQ no tie line due to worsening weather and time limit, pls use 3565's
3581G	BLK 42eN; 42eP; 42eQ	2BLK42NPQ341A	MCE Baliguas	December 7, 2015	Covered voids over BLK42eQ. Completed BLK42eP and surveyed 2 line of BLK42eN.
3585G	BLK 42eN	2BLK42Nv342A	JM Almalvez	December 8, 2015	Completed BLK42eN with voids due to clouds; Covered voids over Rio Tuba

LAS BOUNDARIES PER FLIGHT

Flight No.:	3573G	
Area:	BLK 42eO, BLK 42L, BLK 42M	
Mission Name:	2BLK42Ov339A	
Parameters:	Altitude: 600/850 m;	Scan Frequency: 40 Hz;
Scan Angle:	25 deg;	Overlap: 30%

LAS

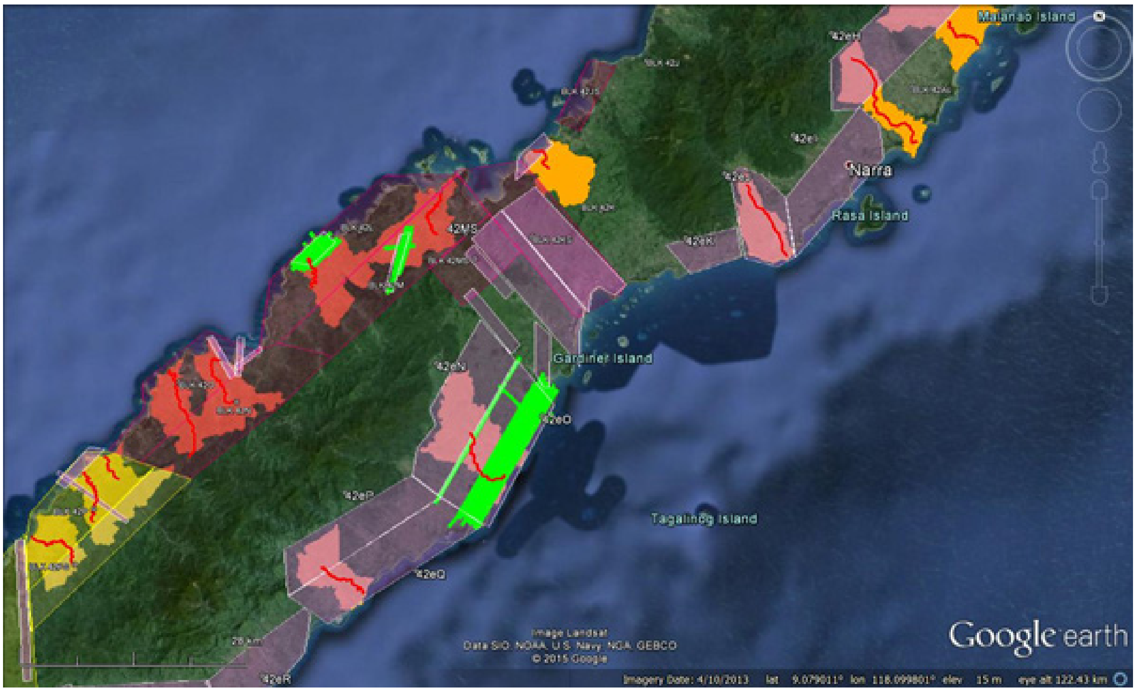


Figure A-7.1. Swath Coverage of Mission 2BLK42Ov339A

Flight No.:	3575G	
Area:	BLK 42eO, BLK 42eQ	
Mission Name:	2BLK42OQ339B	
Parameters:	Altitude: 600/850 m;	Scan Frequency: 40 Hz;
Scan Angle:	25 deg;	Overlap: 30%

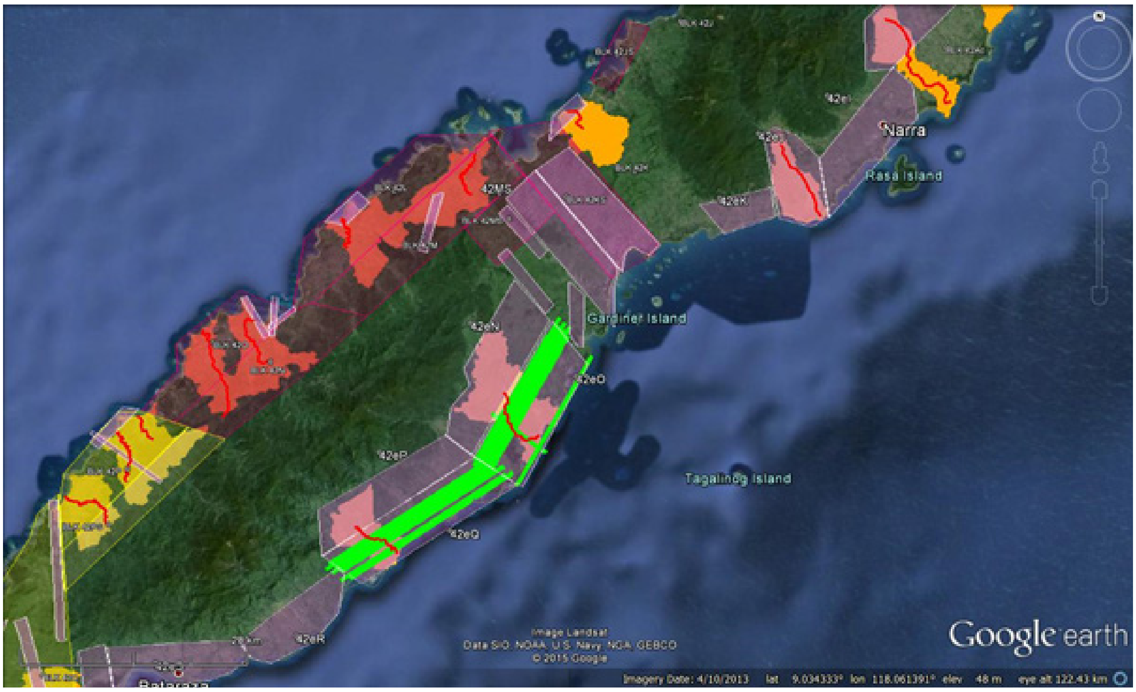


Figure A-7.2. Swath Coverage of Mission 2BLK42OQ339B

Flight No.:	3581G	
Area:	BLK 42eN, BLK 42eP, BLK 42eQ	
Mission Name:	2BLK42NPQ341A	
Parameters:	Altitude: 600/850/1000 m;	Scan Frequency: 40/50 Hz;
Scan Angle:1	3/25 deg;	Overlap: 30%

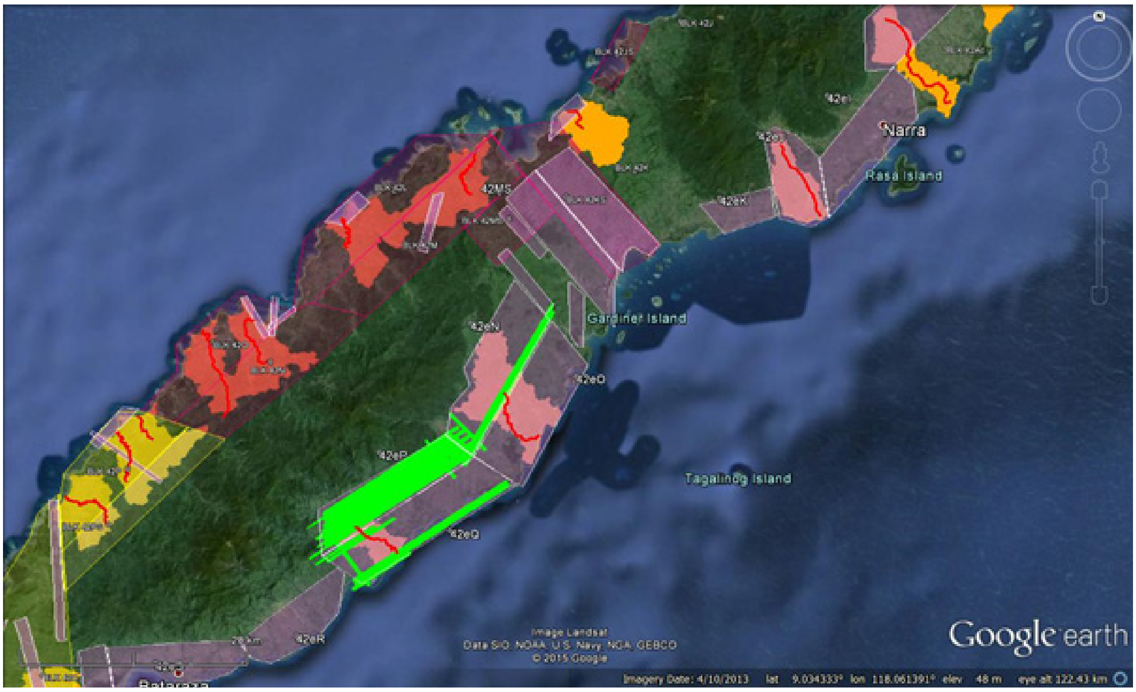


Figure A-7.3. Swath Coverage of Mission 2BLK42NPQ341A

Flight No.:	3585G	
Area:	BLK 42eN	
Mission Name:	2BLK42Nv342A	
Parameters:	Altitude: 500/600/700/850/1000 m;	Scan Frequency: 40/50 Hz;
Scan Angle: 1	5/20/25 deg;	Overlap: 30%

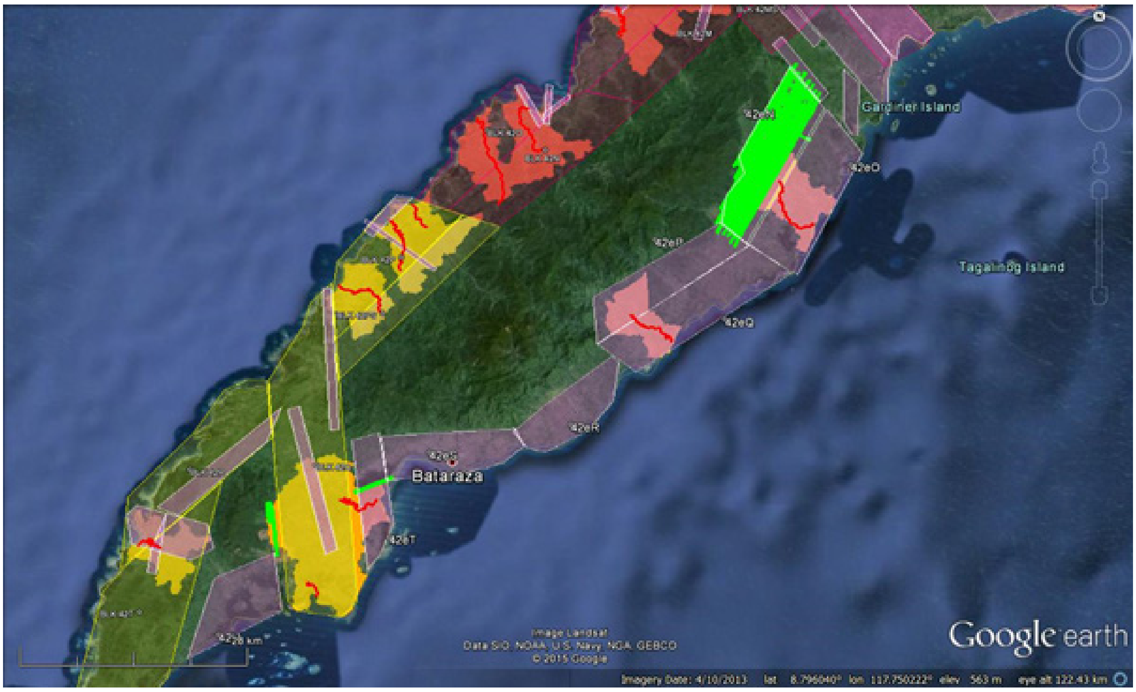


Figure A-7.4. Swath Coverage of Mission 2BLK42Nv342A

Annex 8. Mission Summary Reports

Table A-8.1. Mission Summary Report for Mission Blk42eN

Flight Area	Pagadian
Mission Name	Blk42eN
Inclusive Flights	3585G
Range data size	23 GB
Base data size	5.29 MB
POS	234 MB
Image	NA
Transfer date	January 5, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	Yes
Baseline Length (<30km)	Yes
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	0.81
RMSE for East Position (<4.0 cm)	0.66
RMSE for Down Position (<8.0 cm)	1.87
Boresight correction stdev (<0.001deg)	NA
IMU attitude correction stdev (<0.001deg)	NA
GPS position stdev (<0.01m)	NA
Minimum % overlap (>25)	24.89%
Ave point cloud density per sq.m. (>2.0)	5.95
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	184
Maximum Height	521.73 m
Minimum Height	51.32 m
Classification (# of points)	
Ground	57,214,374
Low vegetation	57,812,094
Medium vegetation	372,915,076
High vegetation	359,201,485
Building	12,451,665
Ortophoto	No
Processed by	Engr. Don Matthew Banatin, Engr. JovelleAnjeanette Canlas, Engr. Krisha Marie Bautista

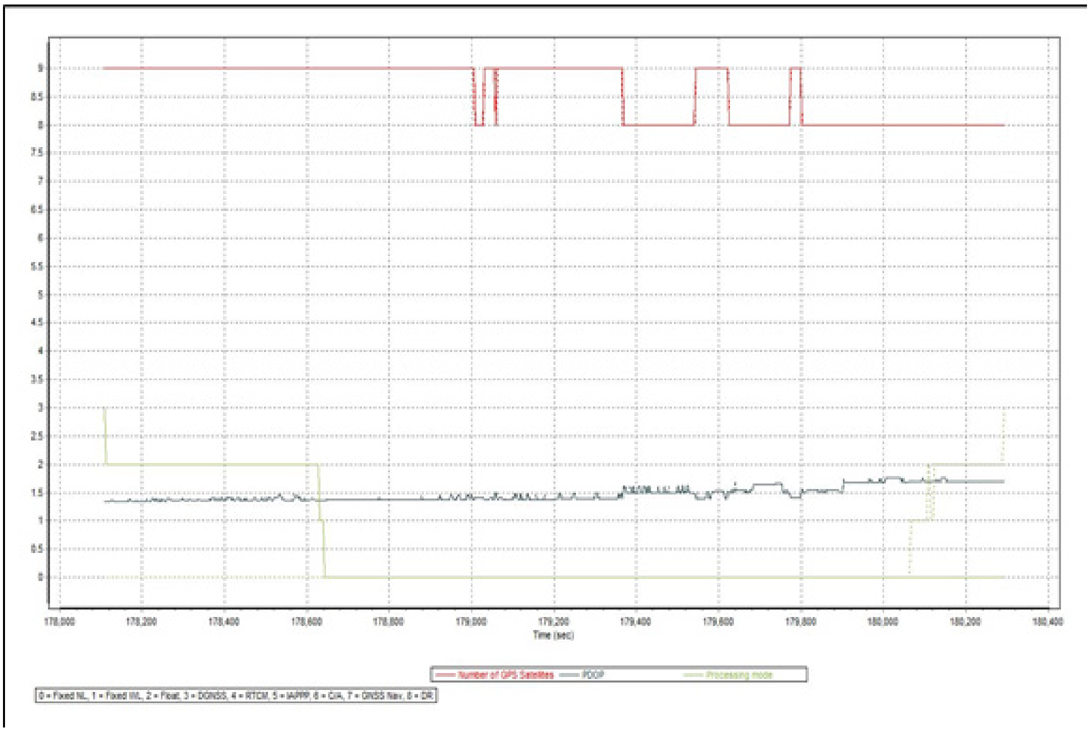


Figure A.8.1. Solution Status

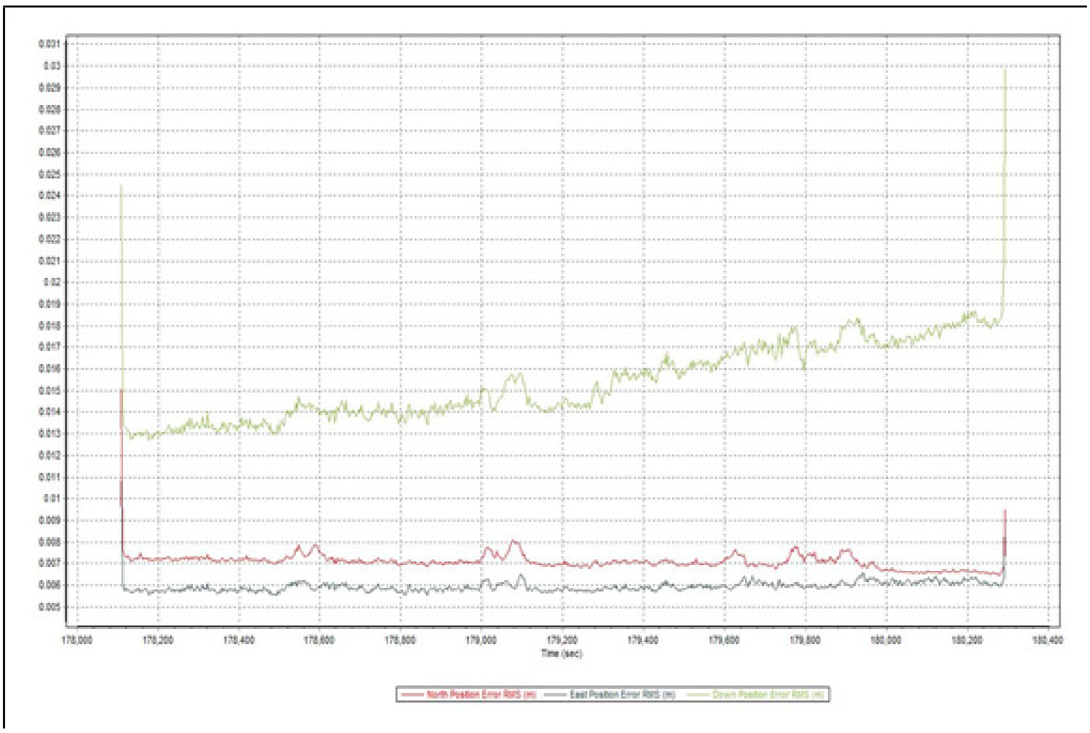


Figure A.8.2. Smoothed Performance Metric Parameters

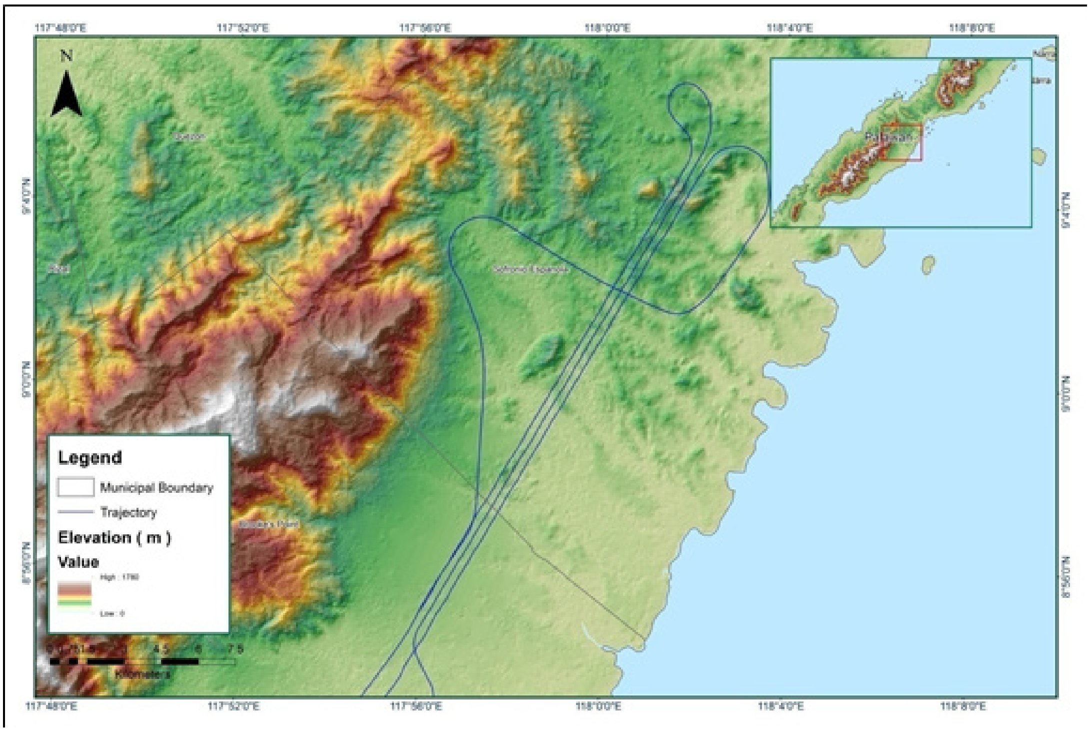


Figure A.8.3. Best Estimated Trajectory

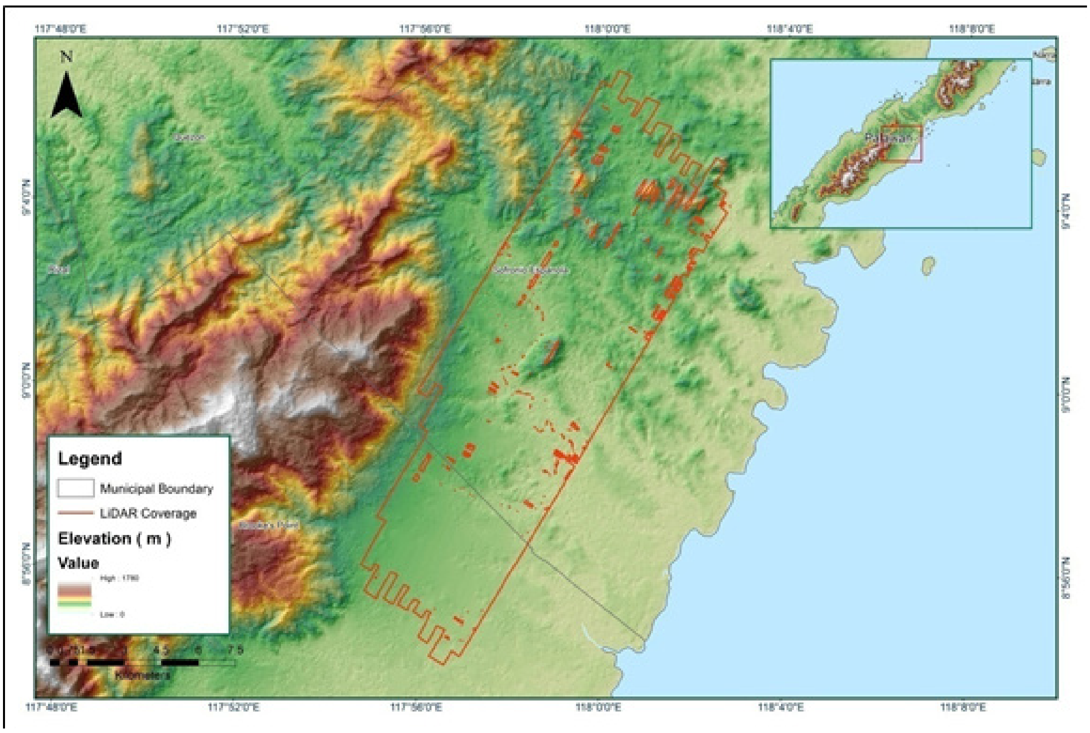


Figure A.8.4. Coverage of LiDAR data

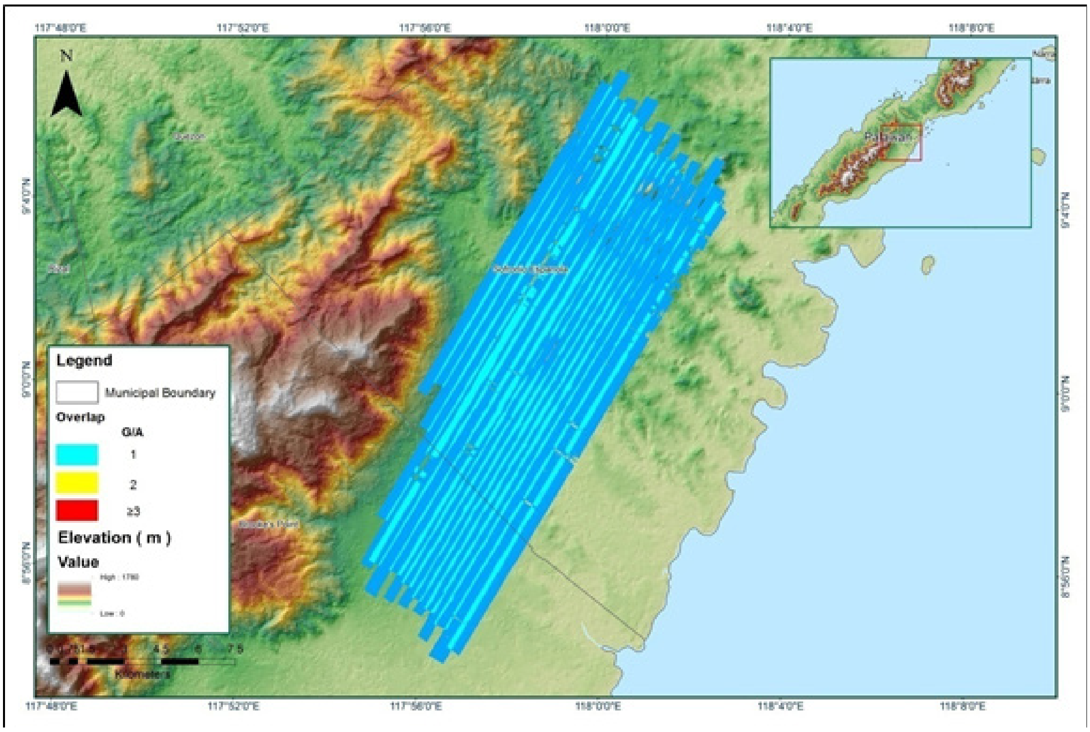


Figure A.8.5. Image of data overlap

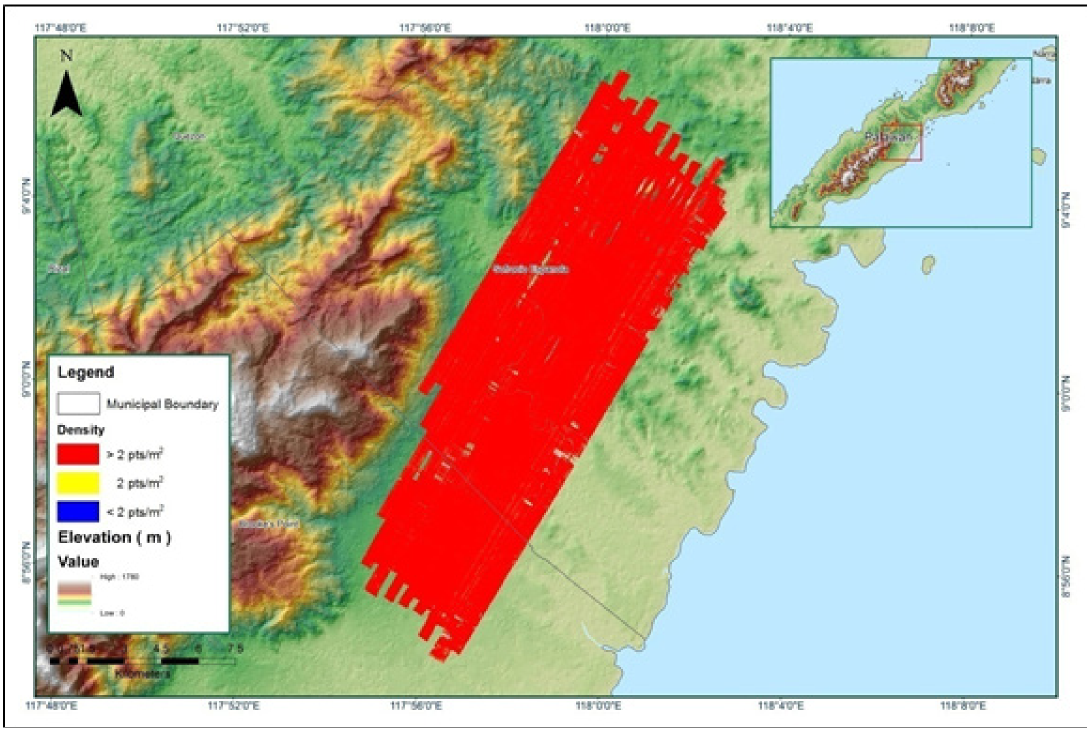


Figure A.8.6. Density map of merged LiDAR data

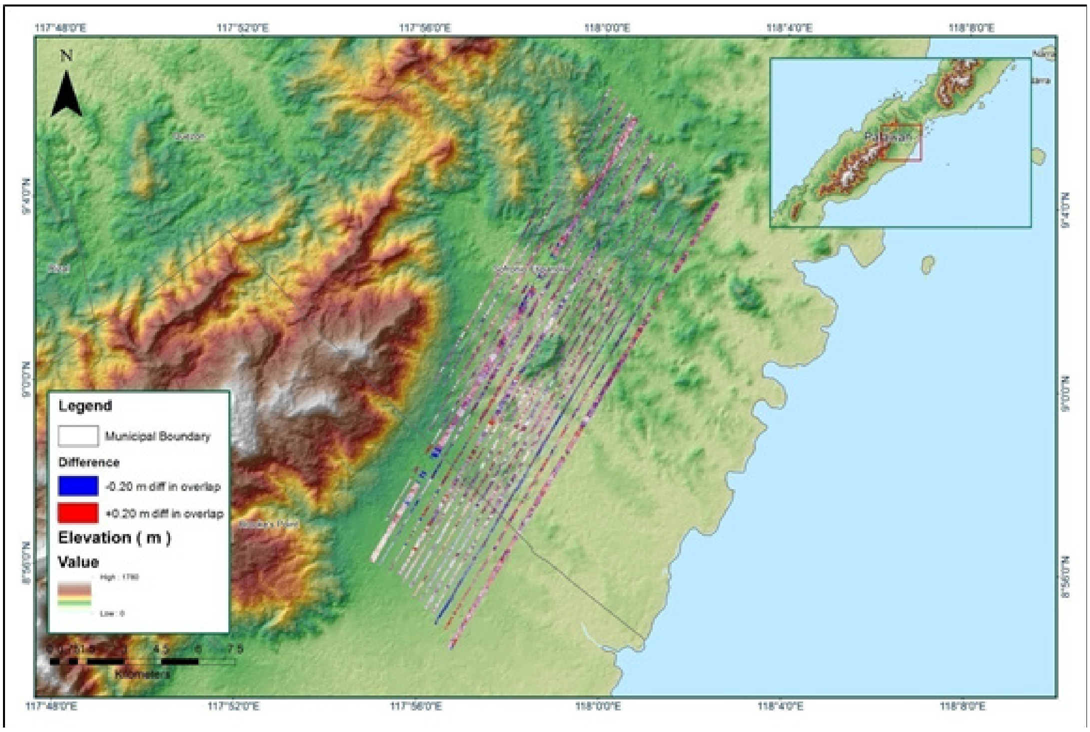


Figure A.8.7.Elevation difference between flight lines

Table A-8.2. Mission Summary Report for Mission Blk42eO

Flight Area	Pagadian
Mission Name	Blk42eO
Inclusive Flights	3573G, 3575G
Range data size	22.3 GB
Base data size	24.2 MB
POS	218 MB
Image	NA
Transfer date	January 5, 2016
Solution Status	
Number of Satellites (>6)	Yes
PDOP (<3)	No
Baseline Length (<30km)	No
Processing Mode (<=1)	Yes
Smoothed Performance Metrics (in cm)	
RMSE for North Position (<4.0 cm)	2.90
RMSE for East Position (<4.0 cm)	2.03
RMSE for Down Position (<8.0 cm)	3.87
Boresight correction stdev (<0.001deg)	0.000283
IMU attitude correction stdev (<0.001deg)	0.001466
GPS position stdev (<0.01m)	0.0094
Minimum % overlap (>25)	30.43%
Ave point cloud density per sq.m. (>2.0)	5.79
Elevation difference between strips (<0.20 m)	Yes
Number of 1km x 1km blocks	191
Maximum Height	340.96 m
Minimum Height	42.92 m
Classification (# of points)	
Ground	55,530,801
Low vegetation	71,940,316
Medium vegetation	267,584,953
High vegetation	318,669,225
Building	5,598,291
Ortophoto	No
Processed by	Engr. Jennifer Saguran, Engr. Ma. Joanne Balaga, Engr. Elainne Lopez

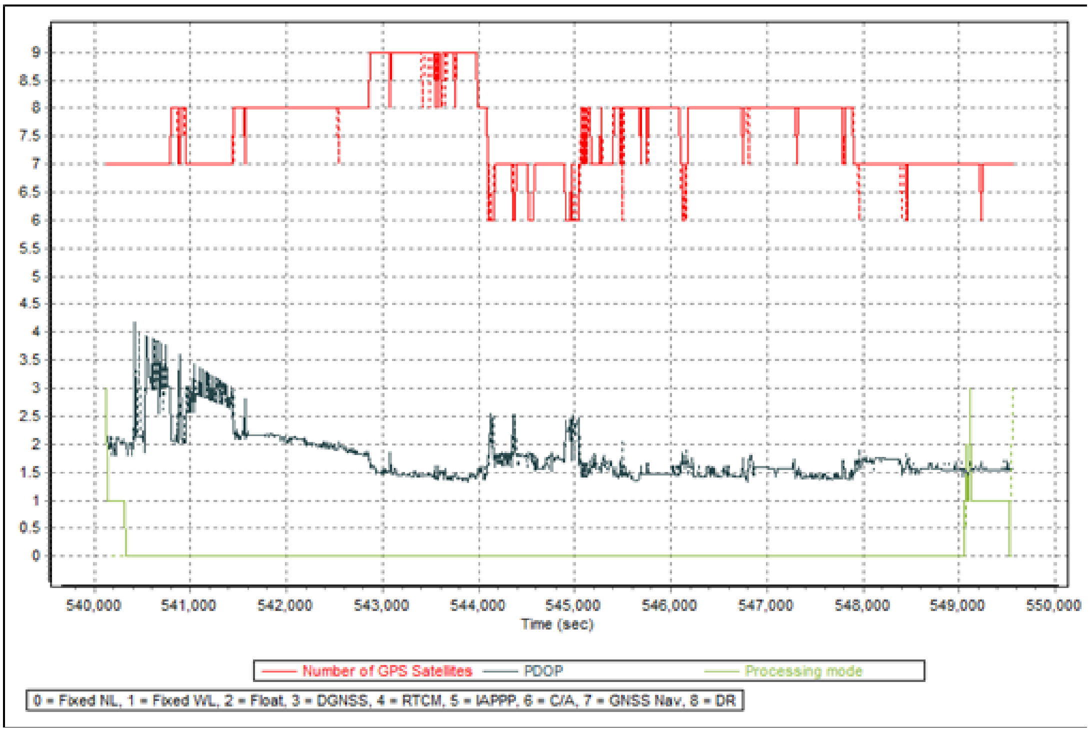


Figure A.8.8. Solution Status

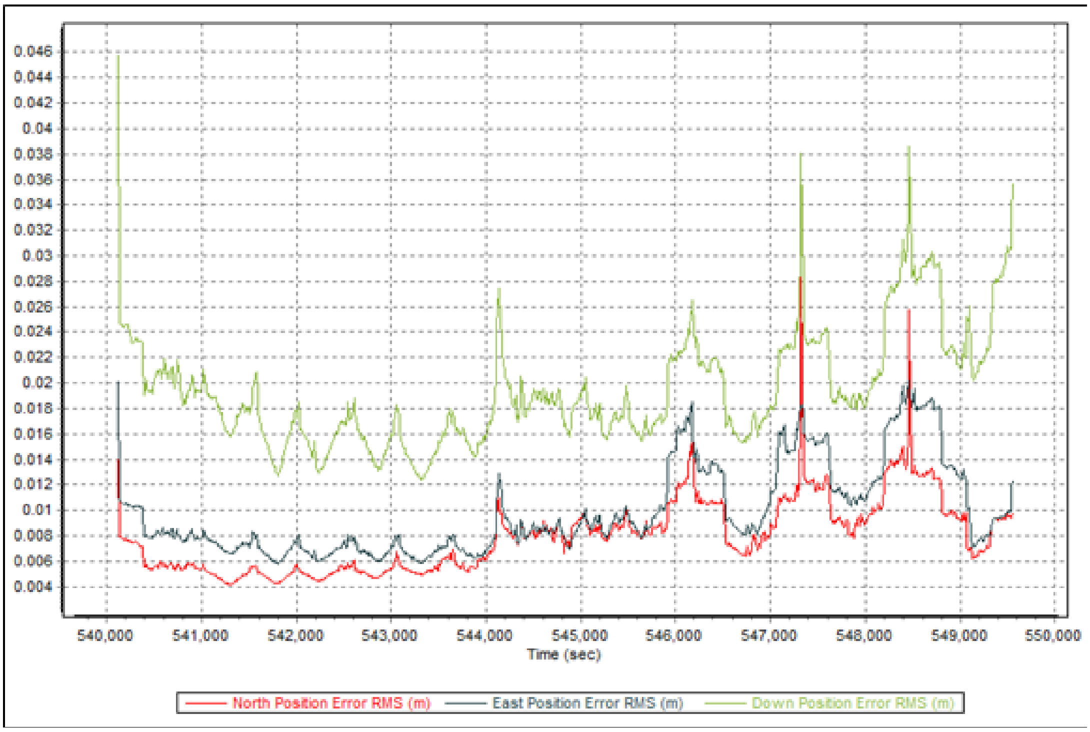


Figure A.8.9. Smoothed Performance Metric Parameters

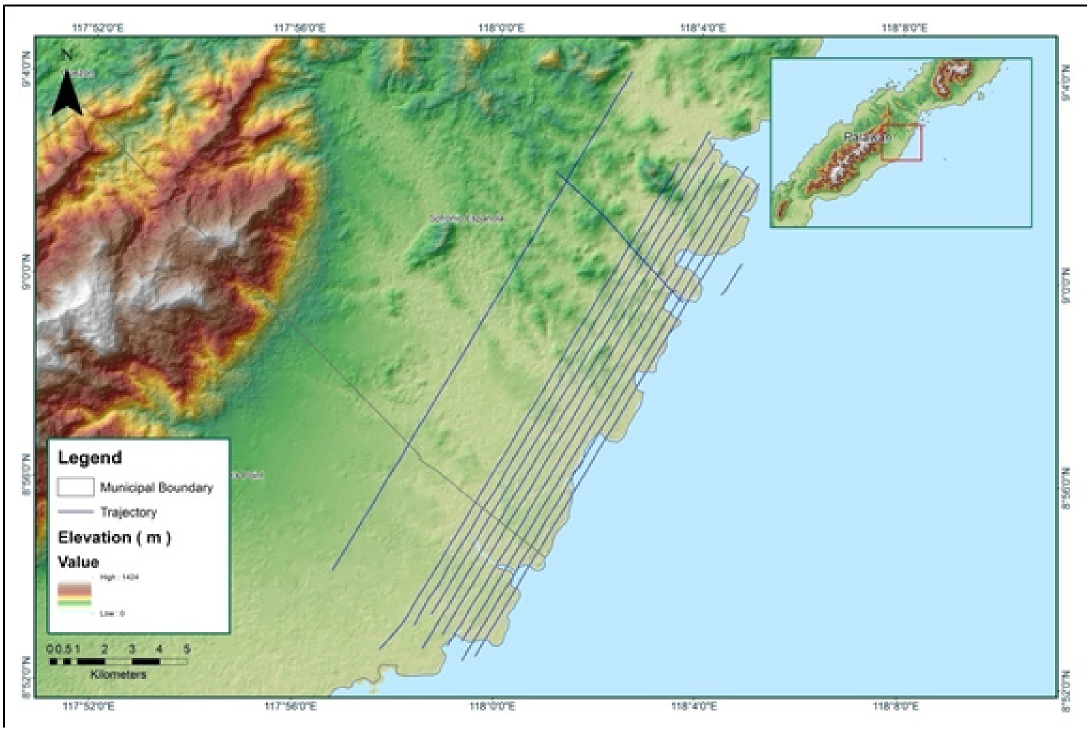


Figure A.8.10. Best Estimated Trajectory

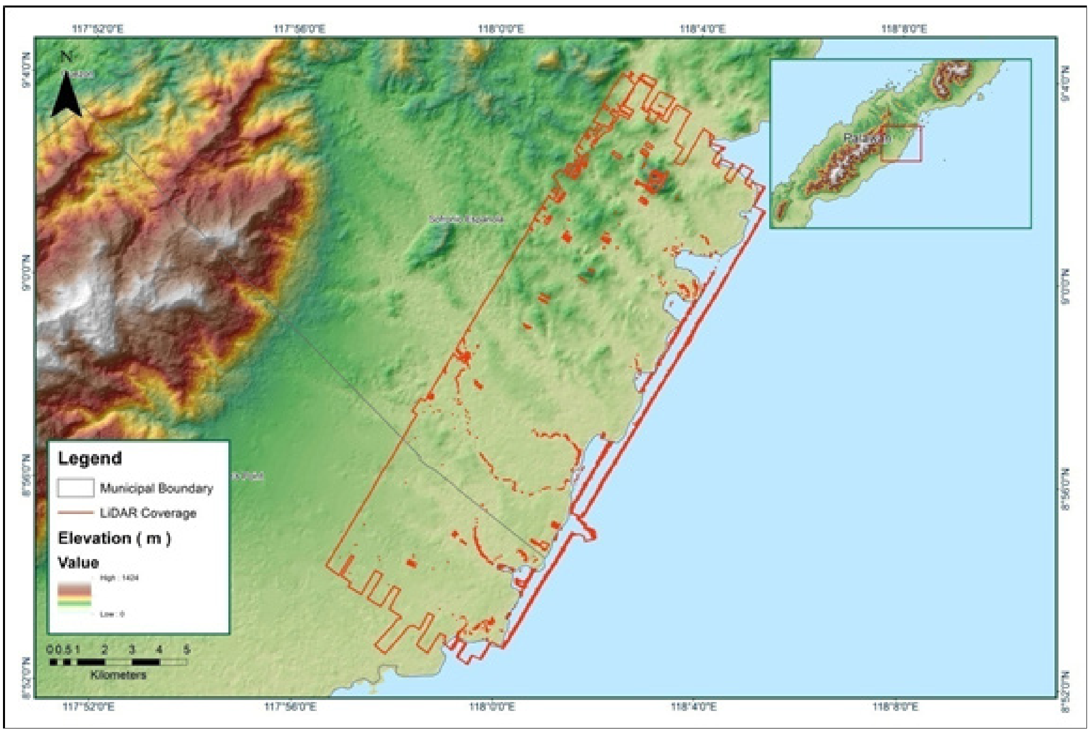


Figure A.8.11. Coverage of LiDAR data

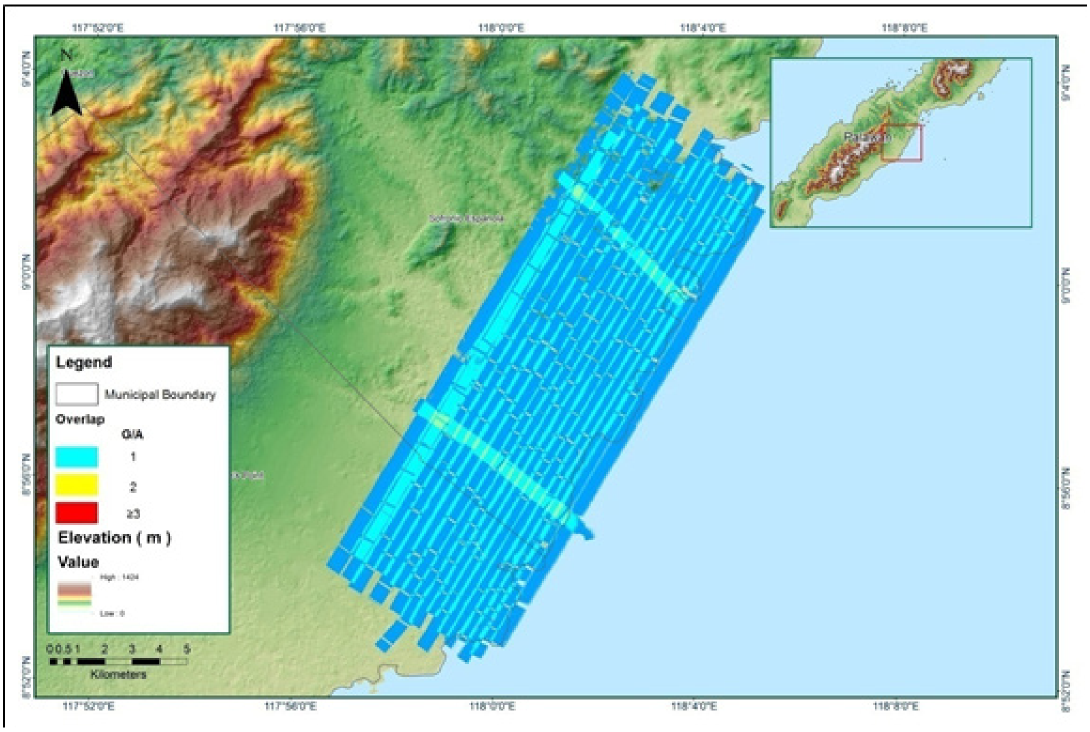


Figure A.8.12. Image of data overlap

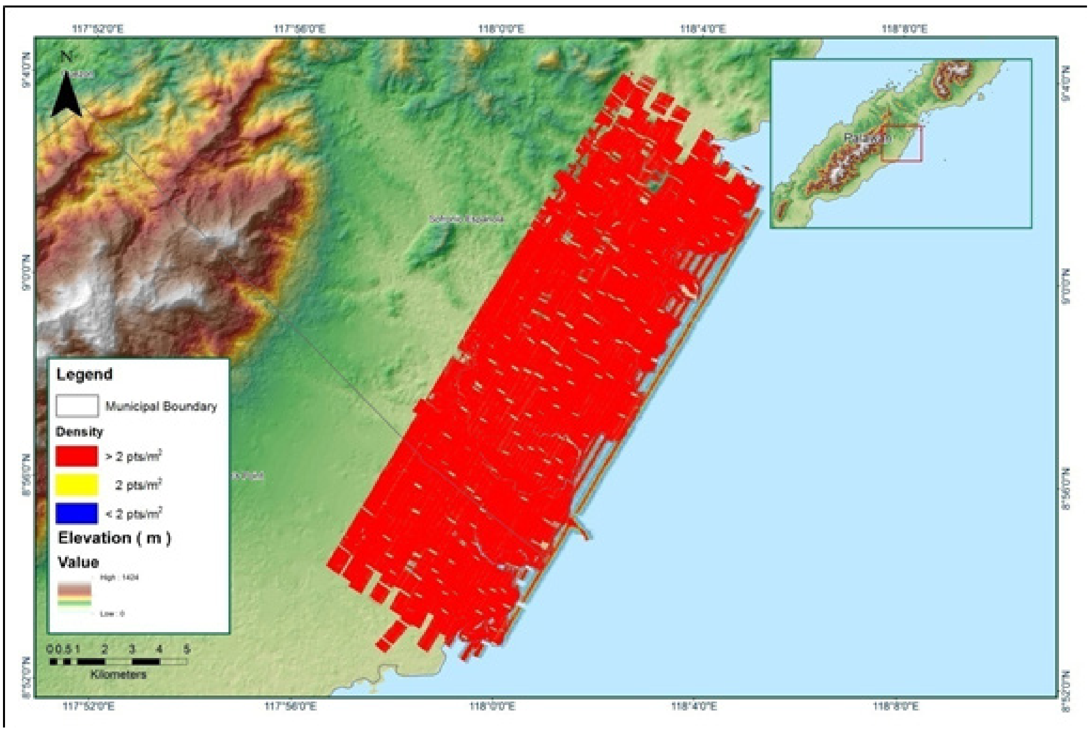


Figure A.8.13. Density map of merged LiDAR data

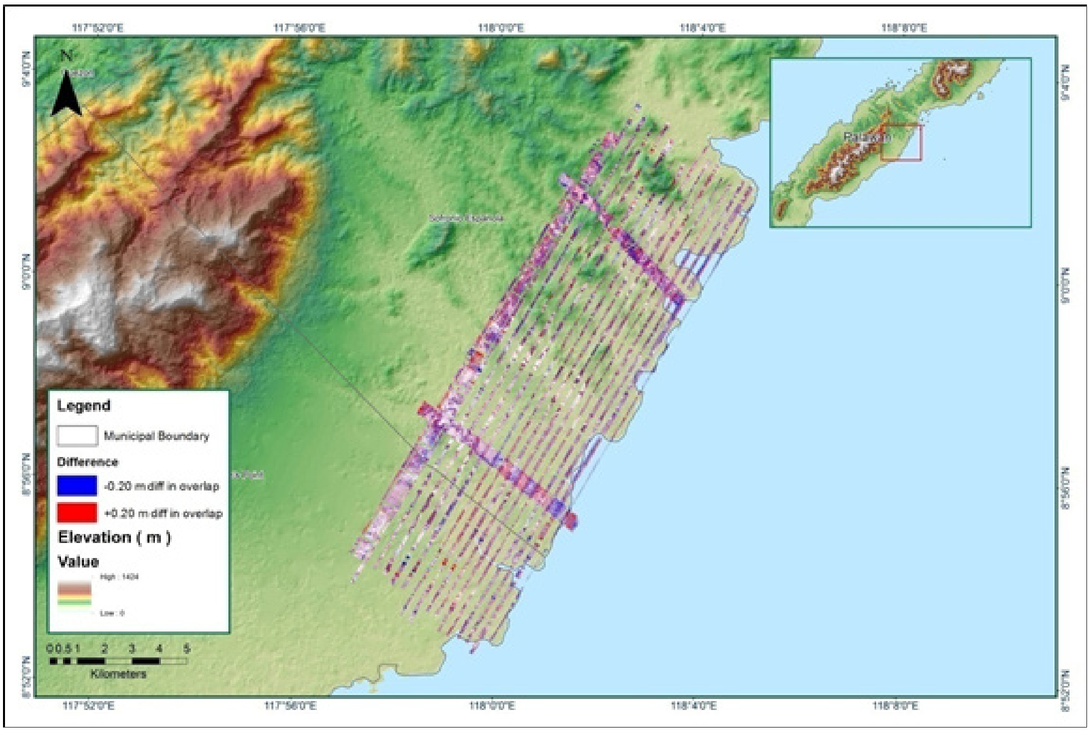


Figure A.8.14. Elevation difference between flight lines

Annex 9. Pulot Model Basin Parameters

Table A-9.1. Pulot Model Basin Parameters

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W1000	1.55	89	0.0	1.098	1.792	0.0102	1	0.5
W1010	0.26372	99	0.0	0.0643533	0.068582	0.0094	0.38341	0.18261
W1050	1.55	89	0.0	1.084	1.769	0.0296	1	0.5
W1060	2.7412	82.247	0.0	4.514	7.3668	0.2737	1	0.30134
W500	0.17861	99	0.0	2.8624	0.61445	0.0657	0.27731	0.17504
W510	0.44435	99	0.0	3.178	0.97439	0.1841	1	0.1313
W520	1.6512	98.908	0.0	1.9487	0.39211	0.0454	0.59283	0.67684
W530	4.436	99	0.0	4.1651	4.7762	0.4050	1	0.285
W540	0.64497	99	0.0	1.8844	0.29641	0.0603	0.40096	0.19085
W550	2.3537	99	0.0	7.5461	4.0001	0.3873	1	0.20913
W560	3.1849	98.928	0.0	1.2986	2.6472	0.1311	0.99143	0.44217
W570	1.8549	99	0.0	4.0164	0.94639	0.0362	0.99556	0.12351
W580	5.1241	99	0.0	4.277	4.9495	0.1637	1	0.2976
W590	0.13559	99	0.0	3.7251	0.58642	0.0157	0.28287	0.19485
W600	0.070637	99	0.0	0.84546	0.43794	0.0525	0.36636	0.68869
W610	0.0929975	99	0.0	0.70749	0.48037	0.0108	0.1152	0.42666
W620	1.4667	98.727	0.0	1.5965	1.1933	0.0522	0.57142	0.89031
W630	0.19016	99	0.0	0.46774	0.17774	0.0149	0.24941	0.35829
W640	4.8397	99	0.0	11.191	4.2425	0.3230	1	0.47398
W650	0.088	99	0.0	2.1219	0.35125	0.0126	0.26853	0.23745
W660	4.5377	99	0.0	11.926	2.705	0.0752	1	0.2152
W670	4.4633	99	0.0	4.7122	0.84188	0.0894	1	0.21344

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W680	5.6835	99	0.0	2.8933	7.6479	0.2043	1	0.49
W690	9.8599	99	0.0	2.4587	3.1461	0.1036	1	0.3013
W700	1.0965	99	0.0	1.909	0.31342	0.0579	0.39329	0.27374
W710	4.777	99	0.0	4.084	4.3231	0.1648	1	0.2893
W720	5.1143	99	0.0	2.576	4.2807	0.1198	1	0.2894
W730	7.8806	79.643	0.0	0.3925	1.1062	0.0216	0.43726	0.0949
W740	0.11607	99	0.0	1.4493	1.8231	0.0665	0.95198	0.12264
W750	0.0277136	99	0.0	3.8263	1.4092	0.0258	0.61719	0.41464
W760	0.12741	99	0.0	0.10238	0.0167	0.0007	0.1829	1
W770	5.925	99	0.0	4.7834	4.4504	0.1663	1	0.4209
W780	8.0545	94.192	0.0	1.4556	1.1601	0.0171	0.39536	0.88186
W790	9.0753	58.323	0.0	3.2893	5.3682	0.3169	1	0.4706
W800	4.9892	99	0.0	4.6653	0.80223	0.0434	0.95895	0.18657
W810	11.76	99	0.0	1.0919	1.2887	0.0845	0.43725	0.0915
W820	7.8768	99	0.0	3.8921	1.5951	0.0956	1	0.2008
W830	0.25882	99	0.0	0.72942	0.12952	0.0600	0.35723	0.47872
W840	2.6078	97.414	0.0	4.7599	4.0496	0.2053	1	0.27794
W850	0.29104	99	0.0	0.62963	0.11297	0.0024	0.24323	0.50048
W860	0.19018	99	0.0	0.0674	1.124	0.0684	0.58056	0.18866
W870	3.7973	98.813	0.0	10.279	3.387	0.1105	1	0.40855
W880	10.35	55	0.0	0.92518	1.5099	0.0622	1	0.5
W890	6.8485	64.966	0.0	1.3504	2.2038	0.1073	1	0.5
W900	10.35	55	0.0	1.7044	2.7815	0.1130	1	0.5
W910	6.9287	64.701	0.0	1.6555	2.7018	0.0842	1	0.5
W920	3.55	78	0.0	0.73498	1.1995	0.0116	1	0.5

Basin Number	SCS Curve Number Loss			Clark Unit Hydrograph Transform		Recession Baseflow		
	Initial Abstraction (mm)	Curve Number	Impervious (%)	Time of Concentration (HR)	Storage Coefficient (HR)	Initial Discharge (M3/S)	Recession Constant	Ratio to Peak
W930	0.28688	99	0.0	0.29285	0.64699	0.1464	0.5358	0.31594
W940	0.0120889	99	0.0	0.0792	3.8634	0.0373	1	0.40857
W970	0.0564489	99	0.0	0.0912028	2.0272	0.1149	1	0.4114
W980	1.5115	89.365	0.0	4.6376	7.5685	0.1395	1	0.5

Annex 10. Pulot Model Reach Parameters

Table A-10.1. Pulot Model Reach Parameters

Reach Number	Muskingum Cunge Channel Routing						
	Time Step Method	Length (m)	Slope	Manning's n	Shape	Width	Side Slope
R1020	Automatic Fixed Interval	841.54	.0006991178	.000486005	Trapezoid	25	1
R1080	Automatic Fixed Interval	9782.9	0.0091812	0.04	Trapezoid	25	1
R120	Automatic Fixed Interval	423.85	0.0050140	0.0058387	Trapezoid	25	1
R130	Automatic Fixed Interval	986.69	0.0085783	.000557411	Trapezoid	25	1
R140	Automatic Fixed Interval	687.99	0.0258621	0.0008518	Trapezoid	25	1
R150	Automatic Fixed Interval	10361	0.0097790	.000544722	Trapezoid	25	1
R160	Automatic Fixed Interval	1851.2	.0003041109	0.0017104	Trapezoid	25	1
R180	Automatic Fixed Interval	6843.4	0.0598022	0.0048138	Trapezoid	25	1
R220	Automatic Fixed Interval	3574.3	0.0023458	0.0029286	Trapezoid	25	1
R250	Automatic Fixed Interval	835.98	0.0104338	.000364192	Trapezoid	25	1
R260	Automatic Fixed Interval	1131.2	0.0052918	.000832055	Trapezoid	25	1
R270	Automatic Fixed Interval	122.43	1.33712E-5	.000348171	Trapezoid	25	1
R290	Automatic Fixed Interval	641.13	0.0040651	0.0026441	Trapezoid	25	1
R30	Automatic Fixed Interval	1246.1	0.0181735	0.0001	Trapezoid	25	1
R310	Automatic Fixed Interval	2023.4	0.0168819	.000364475	Trapezoid	25	1
R330	Automatic Fixed Interval	2492.1	0.0049797	0.0010806	Trapezoid	25	1
R350	Automatic Fixed Interval	523.85	0.0232918	0.0001	Trapezoid	25	1
R410	Automatic Fixed Interval	387.28	0.0113542	0.04	Trapezoid	25	1
R420	Automatic Fixed Interval	4134.3	0.0627420	0.04	Trapezoid	25	1
R440	Automatic Fixed Interval	5192.9	0.0029267	0.0001	Trapezoid	25	1
R450	Automatic Fixed Interval	1618.8	0.0029267	.000351587	Trapezoid	25	1

R470	Automatic Fixed Interval	1321.2	0.0050915	0.04	Trapezoid	25	1
R480	Automatic Fixed Interval	1276.4	0.0081453	0.04	Trapezoid	25	1
R490	Automatic Fixed Interval	4260.5	.0006991178	0.04	Trapezoid	25	1
R60	Automatic Fixed Interval	724.26	0.0088694	0.0103461	Trapezoid	25	1
R80	Automatic Fixed Interval	783.55	0.0115683	0.0011967	Trapezoid	25	1

Annex 11. Pulot Field Validation Points

Table A-11.1. Pulot Field Validation

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
1	8.92777	118.0102	1.21	1.3	0.09	Yolanda	Nov. 2013	25-Year
2	8.928278	118.0118	1.25	1.25	0	Yolanda	Nov. 2013	25-Year
3	8.928631	118.0129	1.4	1.75	0.35	Yolanda	Nov. 2013	25-Year
4	8.928984	118.0087	0.62	0.77	0.15	Yolanda	Nov. 2013	25-Year
5	8.929183	118.0124	0.03	1	0.97	Nina	Dec. 2016	25-Year
6	8.929186	118.0124	0.03	0	-0.03			25-Year
7	8.929767	118.0118	0.03	1.5	1.47	Nina	Dec. 2016	25-Year
8	8.930127	118.0117	0.72	1.2	0.48	Nina	Dec. 2016	25-Year
9	8.93032	118.0124	0.73	1.5	0.77	Nina	Dec. 2016	25-Year
10	8.930818	118.0103	0.6	0.8	0.2	Nina	Dec. 2016	25-Year
11	8.930954	118.0109	0.4	1.2	0.8	Nina	Dec. 2016	25-Year
12	8.930984	118.0107	0.64	0	-0.64			25-Year
13	8.931389	118.0101	0.7	0.8	0.1	Nina	Dec. 2016	25-Year
14	8.932057	118.0094	0.42	1.1	0.68	Nina	Dec. 2016	25-Year
15	8.932154	118.0095	0.31	0	-0.31			25-Year
16	8.932445	118.009	0.32	0.6	0.28	Nina	Dec. 2016	25-Year
17	8.932649	118.0088	0.34	0.6	0.26	Nina	Dec. 2016	25-Year
18	8.932778	118.0089	0.31	0.5	0.19	Nina	Dec. 2016	25-Year
19	8.933242	118.0094	0.2	0.6	0.4	Ondoy	Sept. 2009	25-Year
20	8.933233	118.008	0.15	0.5	0.35	Yolanda	Nov. 2013	25-Year
21	8.933348	118.0084	0.5	0.9	0.4	Nina	Dec. 2016	25-Year
22	8.933393	118.0096	0.42	0.3	-0.12	Nina	Dec. 2016	25-Year
23	8.933566	118.0098	0.38	0.3	-0.08	Yolanda	Nov. 2013	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
24	8.934117	118.0074	0.37	0.4	0.03	Nina	Dec. 2016	25-Year
25	8.934225	118.0099	0.54	0.3	-0.24	Nina	Dec. 2016	25-Year
26	8.934798	118.0064	0.58	0.9	0.32	Sarika	Oct. 2016	25-Year
27	8.935094	118.0055	0.8	0	-0.8			25-Year
28	8.935311	118.0047	0.87	0	-0.87			25-Year
29	8.935762	118.0032	0.68	0	-0.68			25-Year
30	8.936643	118.0022	0.67	0	-0.67			25-Year
31	8.936973	118.0124	0.6	0.35	-0.25	Nina	Dec. 2016	25-Year
32	8.938011	118.0012	0.27	0	-0.27			25-Year
33	8.93927	118.0002	0.72	0	-0.72			25-Year
34	8.941679	117.9987	0.42	0	-0.42			25-Year
35	8.942413	117.9983	0.59	0	-0.59			25-Year
36	8.943867	117.9972	0.48	0	-0.48			25-Year
37	8.945013	117.9966	0.81	0	-0.81			25-Year
38	8.945575	117.9962	0.67	0	-0.67			25-Year
39	8.949043	117.9942	0.65	0	-0.65			25-Year
40	8.949684	117.9939	0.61	0	-0.61			25-Year
41	8.950882	117.9932	0.6	0	-0.6			25-Year
42	8.951351	117.9931	0.4	0	-0.4			25-Year
43	8.951991	117.9935	0.47	0	-0.47			25-Year
44	8.952539	117.9924	1.14	0	-1.14			25-Year
45	8.953122	117.9943	0.64	0	-0.64			25-Year
46	8.959835	117.9897	1.46	1	-0.46	Sarika	Oct. 2016	25-Year
47	8.959934	117.9895	1.22	0.9	-0.32	Nina	Dec. 2016	25-Year
48	8.960031	117.9885	0.65	0.45	-0.2			25-Year
49	8.960326	117.9893	1.68	0.95	-0.73	Sarika	Oct. 2016	25-Year
50	8.960384	117.9899	1.66	0	-1.66			25-Year
51	8.960413	117.9883	0.53	0.4	-0.13	Nina	Dec. 2016	25-Year
52	8.960656	117.9909	1.23	0.2	-1.03	Nina	Dec. 2016	25-Year
53	8.960879	117.9893	1.85	0.7	-1.15	Nina	Dec. 2016	25-Year
54	8.961386	117.9895	1.76	0.55	-1.21	Nina	Dec. 2016	25-Year
55	8.961953	117.9895	1.39	0.3	-1.09	Nina	Dec. 2016	25-Year

Point Number	Validation Coordinates		Model Var (m)	Validation Points (m)	Error	Event	Date	Rain Return / Scenario
	Lat	Long						
56	8.962542	117.9897	1.07	0.3	-0.77	Nina	Dec. 2016	25-Year
57	8.962647	117.9887	1.99	0.27	-1.72	Dindo	Aug. 2016	25-Year
58	8.963312	117.9896	1	0	-1			25-Year
59	8.963301	117.9887	1.97	0.84	-1.13	Nina	Dec. 2016	25-Year
60	8.963318	117.9898	0.7	0.65	-0.05			25-Year
61	8.963747	117.9889	1.76	0	-1.76			25-Year
62	8.965586	117.9898	1.28	0	-1.28			25-Year
63	8.965769	117.9881	1.58	0.4	-1.18		Nov. 2016	25-Year
64	8.967053	117.9886	1.59	0.1	-1.49	Nina	Dec. 2016	25-Year
65	8.97136	117.9997	0.03	0	-0.03			25-Year
66	8.990266	117.9832	0.03	0	-0.03			25-Year
67	8.992606	117.9818	0.03	0	-0.03			25-Year
68	8.999783	117.9788	0.05	0	-0.05			25-Year
69	9.018339	117.9856	0.09	0	-0.09			25-Year
70	9.023317	117.9722	0.11	0	-0.11			25-Year
71	9.023326	117.9705	0.06	0	-0.06			25-Year
72	9.024067	117.977	3.79	0.3	-3.49		Aug. 22, 2016	25-Year
73	9.024376	117.9804	0.06	0	-0.06			25-Year
74	9.02463	117.979	0.69	0	-0.69			25-Year
75	9.024552	117.9618	0.11	0	-0.11			25-Year
76	9.025099	117.9635	1.17	0.52	-0.65		Aug. 2016	25-Year

Annex 12. Phil-LiDAR 1 UPLB Team Composition

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